Robusticity and Rugosity in the Modern Human Skeleton

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Abstract

This is an investigation of the relationships between robusticity and rugosity in the postcranial and cranial skeleton of modern humans. Robusticity is defined here as the strength of an element relative to its size, and refers to the thickness of limb bones for their length, and the relative size of cranial features. Rugosity refers to the surface features of bone, in particular fibrous and fibrocartilaginous entheses. Both data types may provide information about the lives of the individuals to whom the skeletal remains belonged. The two data types may also reflect different remodelling processes in the skeleton.

Demographic and environmental variables are investigated in their influence on global variation in both robusticity and rugosity. Subsistence strategy and sex are shown to be the most significant influences on robusticity and rugosity, once other variables are held constant. Body shape and size also influence both cranial and postcranial size and robusticity. However, both robusticity and rugosity demonstrate considerable individual variation both between and within populations.

The combination of robusticity and rugosity data in the same analyses is novel, and provides a chance to establish whether the two kinds of data reflect the same underlying osteogenic processes. Robusticity and rugosity in the cranial and postcranial skeleton are shown to correlate only in general terms. This demonstrates that despite the two data types being collected from the same skeletons, they do indeed reflect subtle differences in human skeletal response to demographic, ethnic and environmental influences.

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Chapter 1 : Introduction

This thesis reports the findings from research into the factors underlying modern human skeletal variation. The focus is specifically on the assessment of robusticity and rugosity, two characteristics of skeletal elements that may relate to muscular strength, personal experience of environmental or loading stresses, or phylogenetic heritage. The study was designed to assess both robusticity and rugosity independently on relatively complete adult skeletons from a large, global sample, with the intention of comparing the resulting data sets. Thus the relationships between these characteristics can be examined across different regions of the body, and between different regions of the world.

The rest of this chapter provides the context for this study, from the existing literature in biomechanics and osteology. The definitions of robusticity and rugosity are discussed, and the potential sources of modern human variation in robusticity and rugosity are outlined. Both temporal trends within geographic regions and recent spatial variation are examined.

Chapter 2 describes the methodological issues raised with this study, the techniques used for the assessment of robusticity and rugosity, and describes the population samples used and their distribution. An objective and reliable scoring system for postcranial rugosity was developed for this study following considerable pilot work. Four data sets, one each for cranial robusticity, cranial rugosity, and postcranial robusticity and rugosity were produced. They were explored initially using univariate

ANOVA, and other standard methods. Subsequent hypothesis testing used multivariate ANOVA, Principal Components Analysis, and related methods. The rationale behind this research strategy and design is also discussed in Chapter 2.

Chapters 3 to 6 report the results of analyses on each of the four companion data sets, cranial robusticity and rugosity, and postcranial robusticity and rugosity. Results of the univariate and multivariate analyses are presented by age, sex, climate, lifestyle and continent, and as profiles for each major population in the sample. The hypotheses tested in these chapters relate to whether robusticity and rugosity levels are significantly influenced by demographic factors (age and sex), or factors relating to ethnic heritage and individual experience (climate, lifestyle and continent).

Chapter 7 synthesises the results from Chapters 3 to 6 and addresses the further questions related to how the four data types respond to the stresses outlined below. The hypotheses tested in this section relate each of the data types to each other, to establish whether robusticity and rugosity levels covary or correlate within the skeleton. Finally, an attempt is made to discriminate discrete populations on the basis of robusticity and rugosity. This acts as a demonstration of how discriminatory each data type can be, when used alone. It also identifies those populations that may share robusticity or rugosity patterns. In Chapter 8, the major findings of this study are summarised and discussed in relation to previous literature and in relation to the hypotheses outlined initially.

Context and Definition of Terms

The human skeleton has many roles, and provides crucial data for many scientific endeavours. The skeleton must fulfil the functional needs of support and protection for soft tissues, and provide a frame that facilitates locomotion and is resistant to the strains induced by muscular contractions and gravity. It must achieve all this with efficient use of bio-resources, and must maintain the ability to recover and rebuild following injury. Since all skeletons need to fulfil these requirements, a morphological comparison of varied species can highlight phylogenetic influence, bringing together the effects of selection for different locomotor patterns and niches, and the effects of drift between closely related populations. Furthermore, at a more personal level, a skeleton may represent a snapshot of the experience of the individual, recording trauma, developmental perturbations, pathologies and activity patterns in their morphological features.

Bone is a developmentally plastic tissue, responsive to applied mechanical loading, especially in the long bones (Jones et al., 1977, Ruff and Hayes, 1983a, Ruff et al.,1991a, Trinkaus et al., 1994). Therefore, the morphology of preserved and fossil bones should tell us something about the mechanical forces which they were under during life. The key skeletal response to loading stress is to optimise the strength of the stressed element and the energy needed to move it. Bone is deposited where it is required and absorbed from elsewhere in a constant attempt to balance these goals. The deposition of bone in an area under stress acts to decrease the load per

unit of bone in that element. However, the more bone is deposited, the heavier the element is and the more energy it takes to move.

Experimental studies (Lieberman, 1996, Lanyon et al., 1982, Mosley et al., 1997) indicate that the major response to exercise is through geometric modelling and remodelling, rather than through changing the properties of the tissue; such as bone density or sub-structure. This means that bone morphology, particularly the cross sectional area of long bones relative to their length, would indicate the forces they were subject to during life (Carter, 1999). Socio-culturally determined gender- and age-appropriate activity differences may produce variations in bony morphology within and between populations both spatially and temporally (Bridges, 1996, Collier, 1993, Nagy, 1998, Lai and Lovell, 1992).

Other aspects of skeletal morphology that are apparently influenced by either specific activities or general activity levels include diaphyseal shape (Lovejoy et al., 1976, Lovejoy and Trinkaus, 1980), bone torsion (Rhodes, 2002), radial tuberosity orientation (Trinkaus and Churchill, 1988) supernumerary facets (Wilczak, 1998), fossae (Kennedy, 1983) and trauma patterns (Berger and Trinkaus, 1995). All have been used successfully in this context, with the aim generally being to determine the muscle complexes and habitual activities likely to be responsible for such morphological features.

However, it is not just what a person does throughout life that affects his or her skeleton, but where a person lives. Several arguments have been made for the

significant influence of temperature or latitude on skeletal morphology (Pearson, 2000, Riesenfield, 1973, Ruff, 1991, 1994, Holliday, 1995, 1997, Weaver and Ingram, 1969, Houghton, 1991). The climatic influence is generally thought to act on limb length and torso breadth, resulting in changes to stature, body proportions, and robusticity, where calculations rely on size correction using element length. However, climatic parameters exert constraint on the range of subsistence strategies that can be successful in a habitat, and so climate and activity may not be entirely independent as influences on skeletal morphology.

On the other hand, personal activity and environment experience is not the only influence on the skeleton. The general body plan and body shape of a species is under genetic control (Livshits et al., 2002). It also reflects the functional requirements of the niche and phylogenetic heritage. The extent to which this is relevant in within-species comparisons is unclear. However, constraint on remodelling, driven by the need for the body to function as a unified whole, may operate to restrict the degree to which separate elements are able to respond to the loading regime.

With so many different influences on the skeleton, care must be taken that the same data are not used to answer too many different questions (Lieberman, 1997, 1999), since the partitioning of different influences on morphology is not clear. A single trait cannot be used to distinguish between species and subspecies as well as being a variable that is used for understanding lifetime experience of mechanical loading, environmental parameters or socio-demographic lifestyle changes. If analysis of

skeletal morphology is to be statistically rigorous, then all possible influences on the skeleton must be controlled, even in a non-experimental study.

Consistent definitions are important for this analysis, as well as for assessing trends in robusticity in recent human morphological evolution, population migrations and mixing, through the meta-analysis of literature sources. There have been some excellent recent clarifications of the term (Ruff et al., 1993, Pearson, 2000 and commentators), but prior to this robusticity was a general term which could be used to mean either size, thickness of build, ruggedness of surface features, or some holistic combination of all these aspects to imply an individual who is generally strongly built. Robusticity is a deceptively difficult variable to quantify or define, and measurement of robusticity, independently of size, is highly problematic.

The definition produced by Ruff, Trinkaus, Walker and Larsen in 1993 is a useful starting statement. These authors regard robusticity as being the *strength or rigidity of a structure, relative to the mechanically relevant measure of body size.* This is potentially a very broad definition, given that a 'structure' could be a part of a bone, a whole bone, a functional complex or even a whole individual. Furthermore, it is a general statement about the overall structure, and makes no reference to the internal organisation of tissues and their properties within that structure. However, it is a refinement of prior definitions, where the scaling factor was usually considered to be element length. With this definition, these authors highlight the fact that the mechanically relevant measure of size may be a variable other than element length.

If robusticity is then a size-corrected measurement of overall strength or rigidity, a further term is needed to describe the surface characteristics of the same elements. The term used here is rugosity, defined as roughness or ruggedness, which is a term used in the literature to some extent (e.g. Morris, 1997). Like the term robusticity, rugosity can be applied to whole skeletons, individual bones or specific characters on bones. Both operational definitions for this study are detailed below, and the concepts are explored in subsequent sections.

Robusticity: The strength or rigidity of a structure, relative to the mechanically relevant measure of body size

Rugosity: The level of development of the surface features of a structure.

Investigating Robusticity

The definition of robusticity above separates robusticity from size, although in reality distinguishing the two is more complicated. The strength and rigidity of structures of dry long bones can be ascertained in different ways, including through biomechanical experimentation on laboratory animals. Each method provides information about slightly different aspects of robusticity.

Classically, the external dimensions of bones have been compared to each other to produce indices of shape. Robusticity indices usually evaluate the diaphysis or articular surfaces by relating the gross external dimensions of the bone to its length (Trinkaus, 1980, Bass, 1987). As basic descriptions of robusticity, these indices are useful, but a simple index can conceal interesting variables like the relative contributions of different muscle complexes to robusticity. Furthermore, since an index is composed from several variables, change to any one of them can change the index, and identical indices can be produced from dissimilar morphologies. Indices for cranial features are usually aimed at describing shape, as in indices for prognathism, relative cranial height or width.

A more recent approach to the study of robusticity is to characterise the internal morphology of the bone with reference to the muscular forces acting upon it (Ruff et al., 1993, Ruff, 1994, 2000b, Pearson et al., 1998). Cortical thickness, and the relative density and make-up of different regions and types of bone can be evaluated using X-ray, Computerised Tomography and other scanning processes. These

methods have the potential to be extremely informative, but are currently expensive, and they should still be utilised in conjunction with analysis of other characteristics.

Levels of robusticity are presumed to reflect both genetic and environmental influences on the skeleton. These variables are partitioned for ease of discussion, but are in reality linked in complex ways. The genetic influence is thought of as the developmental program that characterises the way in which the bones respond to the stresses imposed upon them. Parameters such as growth and ossification rates might be examples of genetic influence on robusticity, resulting from evolutionary heritage.

Environmental influence may be apparent in several forms, exerting pressure on the developmental program in both positive and negative ways. Variables such as sex, diet, climate, and activity pattern may, via endocrine pathways, influence the rates of bone modelling and remodelling, cause wasting or stunting, or encourage deposition of bone in areas of the skeleton under stress. Increases in robusticity due to exercise may be localised, as suggested by Wolff's law (Bertram and Swartz, 1991, Krahl et al., 1994), or systemic where they may promote increased rates of bone deposition throughout the skeleton (Lieberman, 1996), likely through the influence of growth hormone (Isaakson et al., 1982, Canalis, 1996, Mosekilde et al., 1998). This study has the benefit of having a considerable body of recent literature to draw on.

A bone with a larger diameter has more resistance to bending than a bone with a smaller diameter, even if cortical thickness is the same in both, due to increased

biomechanical efficiency. This has been demonstrated in the Levantine Palaeolithic sites, where the large diameter of the Amud humerus results in high strength or section modulus. This is in comparison to the humeri of Skhul and Qafseh which are much less strong, close to the means for early Arab and Natufian humeri, despite having similar cortical thickness to Amud (Smith et al., 1983). Further increases in long bone bending and torsion strength can be derived from reduction of the medullary cavity, although this results in a larger and heavier mass of bone to support. Distal limb elements may be less able to respond in this way than proximal limb elements, due to gravity constraints (Lieberman et al., 2001). Local remodelling is triggered by dynamic, rather than static strain (Lanyon et al., 1982, Lanyon and Rubin, 1984, Burr et al., 2002), and strain rate rather than strain magnitude (Mosley and Lanyon, 1998).

The cross-sectional shape of the diaphyses may also relate to bone strength, in that thickening in one plane may indicate the habitual direction of strain experienced by that limb (Lovejoy et al., 1976). However, this has been recently challenged by experimental work (Daegling, 2002). Long bone cross-sectional shape may also be affected by age (Feik et al., 2000), as well as by lifestyle changes resulting in different activity patterns, such as shifts in subsistence strategy (Bridges, 1989, Ruff and Hayes, 1983a, 1983b, Larsen, 1995, 1997) or even the tools used (Peterson, 1999).

The effects of muscle loads on the force they transmit through the skeleton depend significantly on the angle of limb flexion, such that it is possible to determine the range of motion and force that a structure is best suited to (Hoher et al., 1999).

Although muscular force is a major stress on bone architecture, it is not the only way in which bones are exposed to force. Gravity imposes force through weight bearing elements of the skeleton as well. Furthermore, regular trauma or violent force could affect bone remodelling.

One important assumption is that the robusticity of a bone reflects more than the immediate activity and environment of the individual just before death. Activity tends to decline with age, and so the bones of people who died in their sixth decade or later might converge towards indicating a more sedentary life than those of younger people, irrespective of other factors. Bone loss with age is documented in both sexes (Ericksen, 1976, 1982, Rutherford and Jones, 1992, Mays, 2000, 2001), however, the rate of cortical bone loss is initially low, and is thought to not become significant until after age 65 (Raisz, 1982). Also, the patterns and levels of robusticity attained by the time cortical bone loss begins are influenced by activities before that. Thus, for our purposes, we can take adult bones and read from them information about the youth and adult life of that individual, not just the preceding month (Robb, 1998).

However, not all populations appear to respond to age in the same way (Martin and Atkinson, 1977, Martin et al., 1985, Mulhern and Van Gerven, 1997). As well as bone loss, there may also be changes in bone density and microstructure with age, such that bone thickness does not have the same relationship with bone strength that it has in a younger individual. The density of Haversian remodelling systems (secondary osteons) in bone is sometimes used for ageing, since the damage that such systems repair is by nature cumulative through life (Martin and Burr, 1982).

However, Haversian remodelling rates are increased by mechanical loading, and are therefore influenced by habitual activity levels during life, as well as genetic predisposition (Kobyliansky et al., 2001). Furthermore, bone mineral density is determined by lean body mass, not fat mass in men (Langendonck et al, 2002) meaning that increased muscle mass from exercise is correlated with increased bone density better than increased mass from fat stores.

At the other end of the lifespan, questions about the ontogeny of robusticity are usually addressed with two aims. Either the aim is to determine when juveniles from archaeological or prehistoric populations began to act as adult workers, or for determining whether robusticity differences between populations can be interpreted as being evidence that they are different species or sub-species. Activity performed before puberty is thought to have a greater impact on robusticity than activity performed as adults, since the skeleton can more readily adapt to functional loading during active growth phases. Older individuals respond to loading by reducing endosteal dimensions, rather than increasing periosteal dimensions (Woo et al., 1981, Ruff et al., 1994), although the degree to which bone mass can be changed in adulthood may be limited (Forwood and Burr, 1993). Diaphyseal robusticity differences between populations may therefore reflect differences in the age at which juveniles are expected to perform adult tasks, and expose themselves to heavy loading on the skeleton. This in turn may reflect the degree to which a population is under ecological stress, such that it can or cannot afford to pamper its juveniles.

At a phylogenetic and taxonomic level, robusticity is a characteristic of skeletons or skeletal elements that may be used as a trait to distinguish between species and subspecies (Duarte et al., 1999, Kramer et al., 2001) Although rarely, if ever, used alone, relative robusticity is nonetheless used as powerful corroborative evidence for differences between operational taxonomic units. Neanderthal infants and children have robust long bones compared to modern human children. Heim (1983) argues that this implies a genetic difference between Neanderthals and Moderns, since young children cannot have had significant experience of loading to produce robusticity responses. On the other hand, differences in diaphyseal robusticity asymmetry between adult Neanderthals and Early Moderns are argued to be functionally based, since the genetic programme must affect both sides of the body equally (Ben-Itzhak et al., 1988).

Robusticity of the epiphyses is linked less to activity patterns and more often to body mass. The epiphyses are presumed to be under stricter genetic control than the diaphyses, since deviation from true joint congruence would have severely deleterious effects on locomotion and other activity. Ruff and colleagues have argued that articulations are less subject to environmental influences than diaphyses, due to functional limitations on the amount of bone remodelling that can take place (Ruff et al., 1991, Ruff et al., 1993).

Where epiphyses do exhibit experimental responses to exercise driven loading, this is most significant at younger ages and in the distal epiphyses of a long bone rather than the proximal ones (Lieberman et al., 2001). This is likely to be because the

proximal and distal epiphyses are different sizes, and the distal ones are usually smaller. The distal elements experience greater loading for their size than the larger proximal elements, and osteogenic responses are more detectable.

In humans, some epiphyseal response to exercise has been noted. Frequent tennis players were reported by Ruff and colleagues (1994) to have significantly larger radial heads on their playing arm than their non-playing arm. However, joint surface area changes are likely to be responses to the requirements of joint mobility, whereas the osseous responses to loading forces at the epiphyses can be at the trabecular level where they are not detectable externally (Rafferty and Ruff, 1994). Robusticity in the cranium is difficult to assess in the same way as postcranial robusticity. Cranial vault thickness is considered to be the variable most comparable to diaphyseal cross-section, while cranio-facial features previously described as robusticity may be better defined as rugosity (and are discussed below). Variation in cranial vault thickness may be due to the systemic effects of exercise, produced via endocrine influences on general osteogenesis, but not directly affected by muscles (Lieberman, 1996). Alternatively, strain produced by the masseter and other masticatory muscles may result in thickening of cranial bone (Bouvier and Hylander, 1981).

Although archaic human species are generally found to have thicker cranial vaults than modern humans, archaic infant and neonate individuals are within the modern range of variation. The difference between the adults must therefore develop during life, for which reasons Lieberman (1996) argues that cranial vault thickness is not a

useful phylogenetic trait. However, the timing and onset of cranial vault thickening, as with any ontogenetic trait, may differ between species and hence be a useful phylogenetic signal.

The sensitivity of cranial form to environmental changes has been much discussed, particularly in relation to cranial size and shape. This is relevant here in providing an estimate of how likely cranial robusticity is to be influenced by environment. The classic studies of Boas (1912), reporting differences in skull form between European immigrants to the US and their American-born children, have recently been challenged (Sparks and Jantz, 2002). Although change between generations is noted, it has been shown using modern statistical tests to be insignificant, especially in comparison with ethnic differences. However, an alternative reassessment regards the claims of Boas to be upheld (Gravlee et al., 2003). Crania may therefore be less plastic in response to the environment than previously reported, which may mean that cranial robusticity may be influenced by the environment only in a limited way, if at all. Furthermore, the immigrant study re-evaluated here does not represent a great deal of environmental shift. Presumably, individuals were living in similar dwellings, eating similar diets and performing similar activities both before and after migration. Any general climatic differences between the areas inhabited in Europe and the US are likely to have been mitigated by clothing and housing, in order to maintain comfortable living environments.

It is therefore clear that age, sex, genetics, climate and lifestyle are all possible sources of skeletal variation, and may interact in determining robusticity levels.

However, the magnitude and nature of the effects may be different on the diaphyses, epiphyses and cranial skeleton.

Investigating Rugosity

While classic indices of robusticity and diaphyseal circularity evaluate the overall morphology of long bones and articular surfaces, they do not show which muscle complexes are responsible for the stress imposed on the bone. To some extent, the direction of strain imposed on a skeletal structure can be ascertained from an investigation of the internal morphology, through CT or X-ray analysis. Trabecular orientation, bone density and osteon activity are all useful information sources, but they are not visible without specialist equipment. The surface features of bone are readily visible and their study does not require invasive or destructive techniques. Studying the relative development of these surface features provides a method to determine the functional causes and implications of robusticity that might not otherwise be apparent.

The surface features of bone will here be discussed under the term musculoskeletal stress markers or MSMs. This term is well established in the literature (Weiss, 2003a, Bridges, 1997, Hawkey and Street, 1992, Nagy, 1998), and includes muscle attachment sites, entheses (tendon attachment sites) and syndesmoses (ligament attachment sites, recently more generally referred to as entheses) (Hawkey and Merbs, 1995). As a source of activity information, MSMs have great potential, but this has so far been explored predominantly on the postcranial skeleton. The utility of the MSM approach on craniofacial rugosity is less well established.

The general effects of force on bone are well documented, and MSMs are the points at which activity force is transmitted to the bone. The periosteum is well vascularised, and blood flow is increased by regular minor stress to the MSM regions (Hawkey and Merbs, 1995). This stimulates osteon remodelling and results in localised hypertrophy (Rufai et al., 1995). However, MSMs are produced in a number of different ways, and the diversity of structures involved in their formation produce variation in the appearance of MSMs. An understanding of the physiological processes involved in MSM production is essential if the results of study are to be interpreted correctly.

Entheses can be classed as fibrous or fibrocartilaginous, with the former described as 'bony' or 'periosteal', depending on whether the tendon attaches directly to the bone or indirectly to it through the periosteum. This classification follows Benjamin et al. (2002), and can be linked to different characteristics of MSMs on dry bone. Fibrous entheses are more common on diaphyses, while fibrocartilaginous entheses are typical at epiphyses and apophyses (Benjamin and Ralphs, 1998). Fibrous periosteal entheses spread the muscle force over a large area, and tend to produce roughened ridges such as the humerus deltoid and femur linea aspera. These have indistinct boundaries, whereas those of fibrocartilaginous entheses are well defined and the MSM surface is smooth. Fibrocartilaginous entheses are arguably more complex, since there are more tissue types involved in them. The smooth boundary of a fibrocartilaginous enthesis is a tidemark between the calcified and uncalcified fibrocartilage in the attaching tendon. An example of a fibrocartilaginous enthesis would be that left by the tendon of popliteus on the femur lateral condyle.

In the archaeological literature, strong forces from muscles are associated with hypertrophy of entheses. A large, rough or pronounced MSM is therefore associated with higher levels of activity in that muscle complex that attaches there (Krogman and Iscan, 1986, Kennedy, 1998). There is, however, a need to distinguish fibrous from fibrocartilaginous entheses when attempting to quantify MSMs. Rugosity can be assessed through a number of methods. Fibrous entheses are best quantified using scoring methods, since their overall outline is indeterminate. MSMs from fibrocartilaginous entheses may be digitised and their area measured (Zumwalt et al, 2000), but scoring is also an appropriate technique for these entheses. The use of casts and photographs for comparative assessment of rugosity is common (Hawkey, 1988, Miles, 1999, Hawkey and Merbs, 1995). Using some of these methods, MSMs have been used as traits in cladistic analysis (Kramer et al, 2001), and comparisons between Neanderthals and modern humans have been attempted (Endo, 1971), although these have not been widely acclaimed as successful.

It is not clear from the biomechanical and histological literature whether it is increased muscle size or strength that produces enlargement at the attachment site. Myostatin-deficient mice have around twice the muscle bulk of controls, and also have greatly enlarged third trochanters on the femora (Hamrick et al., 2000). However, these authors suggest that the enlarged trochanter is not to do with increased muscle strength, but that it develops as a compensatory adjustment in response to the larger muscle during ontogeny.

Tendons and ligaments can repair after injury and respond to exercise or immobilisation by altering their tensile strength (Benjamin and Ralphs, 2000) which implies that they can detect changes in load and respond appropriately. This is usually the production of fibrocartilage in entheses where the angle of the tendon insertion changes during use of the element (Benjamin and Ralphs, 1998), protecting the interface from shear stress. On the humerus, the deltoid tendon experiences little shear stress with arm activity, whereas the tendon for supraspinatus does.

This highlights the fact that some MSMs may develop for reasons other than response to muscle strength. Those found at epiphyses are likely to be records of fibrocartilaginous entheses, where tendons operate in a wide range of angles, or wrap around bony elements. Those tendons attaching along diaphyses are unlikely to experience the same kinds of shear stress and compression, and will terminate in fibrous entheses over large areas. This means that comparing one MSM with another on the same element may be problematic.

Aggregation of MSM scores has been proposed as a method for producing statistically viable results from MSM analysis (Weiss, 2001, 2003a, 2003b). For the reasons outlined above, aggregation may not be ideal, since it conflates scores which may have developed under different kinds of strain. In this study, MSMs derived from fibrous and fibrocartilaginous entheses are treated separately. Indeed, MSMs from fibrous entheses may be preferred as proxies for muscle activity, being less influenced by the orientation that a muscle may be working in, than by the strength of the muscle and the duration it works for.

Much is made of Wolff's Law of bone transformation, and the ability of bone to respond appropriately to the forces it experiences. However, Benjamin and Ralphs (1998) show that tendons and ligaments are also responsive tissues, and muscles are themselves well known to respond to exercise and inactivity. The important question is whether skeletal tissues all respond in the same way to habitual loading amounts and directions. If not, this would mean that assessments of MSMs might measure something subtly different to assessments of robusticity. The study of MSMs and robusticity in the same bodies provide an opportunity to find out whether these two kinds of data correlate.

For the postcrania, this study focuses mainly, but not exclusively, on MSMs from entheses, to avoid the confounding variables outlined above. This is reflected in the operational definition of rugosity stated above. For the cranium, the criteria for rugosity markers are best filled by examining features on the cranio-facial skeleton such as tori and tuberosities.

Lahr has developed a set of scoring methods for assessing these features (Lahr, 1994, 1996), and has determined that although these traits show regional trends, they do not support the Multiregional Model of Modern Human Origins. Furthermore, despite the fact that they were thought to be characteristic of Far East and Australasian crania, some of these traits might be influenced by cranial dimensions and robusticity (Lahr, 1994, Lahr and Wright, 1996). This means that they cannot be considered phylogenetic markers, and may be subject to epigenetic influences. As such they are appropriate for use in this study, although many of these craniofacial

scores do not represent single muscle attachment sites, but are an assessment of the development of superstructures and facial ruggedness from a more complex set of muscles.

The various tori and crests discussed in this study may have direct mechanical roles, related to muscle and ligament attachments, or they may be involved indirectly in stress resistance for the skull structure. Dental loading is the most obvious source of stress on the facial skeleton, and along with nuchal musculature, must be considered an important candidate for the biomechanical forces that shape developing cranial structures (Endo, 1965, Russell, 1985). This model of the skull as being responsive to localised stress is contrasted with the spatial model of cranial form, which suggests that the diversity of expression of some tori is simply due to spatial considerations (Hylander, 1984). In other words, craniofacial superstructures can be seen as being space fillers between other cranial units.

A further possibility is that the level of expression of these craniofacial superstructures represents developmental stress, and is related to changes in bone growth timing relative to brain growth. Under this model, a rugged cranium is described as hyperostotic (Manzi et al., 1996), and is thought to relate to growth rates and life history patterns. This has so far been discussed only with reference to archaic versus modern humans, i.e. at the species level, and not within species or populations.

The relative development of cranial rugosity features may therefore be an expression of developmental stress, biomechanical loading regime, or be produced simply by the fitting together of other craniofacial regions. The assumption made here for both cranial and postcranial data, is that rugosity can be treated as a proxy for muscle activity, which is a proxy for behaviour. However, this is clearly a simplification, and there are many other theoretical issues to consider, such as the ontogeny and persistence of rugosity features, and the relationship of rugosity with robusticity, size and shape.

The ontogeny of rugosity is important, but under-researched, as is an understanding of the duration that MSMs might be maintained. It is important to know how long a feature might be maintained after the cessation of the activity that promoted its development. Bone loss has been demonstrated at rat humeral entheses following denervation and subsequent inactivity of muscles (Dysart et al., 1989). *In vivo* it is likely that MSMs would not disappear quickly, since the same muscle complexes are used for different activities.

Another important issue is the degree at which responsive hypertrophy becomes pathology. Features like evulsion and evulsion fractures, diffuse idiopathic spondylar hyperostosis (DISH) and osteogenic arthritis are readily described as pathological. However, many minor pathologies are very common, and are clearly part of a normal ageing process (Resnick and Niwayama, 1983, Shaibani et al., 1993). Enthesiopathies (pathological changes at entheses), incorporate the above, as well as overuse injuries like tennis elbow and traction periostitis, and may be

inflammatory or degenerative conditions (Benjamin et al, 2002). In essence, clinicians refer to pathologies where archaeologists refer to markers of occupational stress. MSMs may be either of these, or asymptomatic features that would not be considered pathological. In neither clinical or archaeological contexts are there definitions of the range of diversity in human postcranial MSM morphology that can be considered 'normal'. In comparison, diversity in cranial rugosity features is considered normal, and expressive of population membership.

Although MSM analysis has increased in popularity as a forensic tool over the last three decades, data has frequently been presented in a descriptive form, accompanied by inductive reasoning and 'just-so' stories (Kennedy, 1998). Other notes of caution have been sounded regarding the interpretation of MSM data, since the direct linking between an MSM and a particular behaviour is unwarranted (Stirland, 1998). Robb (1998) suggests that the same degree of robusticity or rugosity at any site might be interpreted in different ways biased by the researchers' views on gender-appropriate behaviour. A rugose or robust humerus might be interpreted as weapon use in males or food preparation in females, for example. Furthermore, ritual, play and sport can affect MSMs, as well as general subsistence mode, a factor that may be overlooked in archaeological studies, despite the fact that the experimental literature frequently refers to sports players (Krahl et al., 1994). The same warnings apply for analyses of symmetry in rugosity.

The impact of climate on MSMs may be subtle, but cannot be ignored. Body proportion differences that are adaptations to climate (Holliday, 1996, 1997, 1999,

Holliday and Trinkaus, 1991) may change the operating angles between limb and torso elements and hence alter the lever arms of muscles and tendons, (Trinkaus and Rhoads, 1999). Cultural or genetic adaptations to climatic differences may also explain patterns in MSMs (Wilczak, 1998). Laughlin and colleagues (1991) drew attention to a hypertrophic humerus excavated from an Aleutian mummy cave. Although indirectly, these authors drew attention to climate, age, sex and body proportions as well as specific activity modes in determining the morphology of surface features of bone.

As with robusticity, age has been shown to affect the level of MSM development in sites associated with heavy use or damage (Robb, 1998, Wilczak, 1998, Miles, 1999). The correlation with age may simply be because MSMs develop over time, and that prolonged or habitual repetition of the same loading experiences is necessary to produce changes in their morphology. Certainly, short-term experimental attempts to influence MSM development in laboratory animals have been inconclusive (Zumwalt et al., 2001).

Heritability in MSMs has not been examined in detail, although some cranial features regarded here as MSMs may have been included in studies of the heritability of non-metric traits. It would be extremely hard to separate genetic influence from epigenetic factors, since populations usually share common activity, climate and subsistence regimes. A possible test, outside the scope of this study, would be to examine diaspora populations compared to those remaining at their traditional locale (e.g. Sparks and Jantz, 2002). Although not as well studied as robusticity, it is clear

that the same set of factors may be important in determining human rugosity variation, and thus must be included in this study.

Modern Human Morphological Variation

Once the parameters of modern human diversity in robusticity and rugosity have been established, then they become important and useful traits to examine in the context of modern human origins and population history. However, this analysis needs to be performed in the context of an understanding of general human morphological variation both temporally and spatially.

Modern humans are morphologically variable in size and shape both spatially and temporally. This variation is interesting for several reasons, especially when trends in brain and body can be compared. Several major trends have been well documented in human evolution, of which three are of particular interest in this context. The first is a tendency toward increasing brain size, and the second is a trend towards increasing gracilisation, a decrease in skeletal robusticity over time. Increasing brain size against a stable body mass would result in a third trend towards increasing encephalisation. The timing of these processes is of clear importance. Gracilisation and encephalisation both reflect changes in a morphological variable over time, relative to the same measure - body size.

Cranial variation

Cranial variation amongst human populations, both archaic and recent, is well understood, having been the focus of anthropological, palaeoanthropological and biomechanical research for several decades. The classic study in this arena is that by Howells (1973), a pioneering multivariate analysis of cranial form and population relationships. The use of craniometric data for reconstructing population history in this fashion has been continued by other more recent researchers (e.g. Lahr, 1994, 1995 and 1996, Lahr and Wright, 1996, Brace et al.,1989, Hanihara, 1997 and 2000, and numerous others). While there remain ambiguities and interesting challenges in this field, a general pattern of global cranial variation amongst major populations is clear. For example, Eastern Asian faces have flat frontal and nasal regions compared to those of Europeans, while Sub-Saharan Africans are relatively prognathic compared to other populations (Hanihara, 2000). Melanesians and Patagonians have large and rugged crania, whereas Southeastern and Eastern Asians have small and smooth crania, and European crania are intermediate between these extremes (Lahr and Wright, 1996).

Brain size, as estimated by cranial capacity, increased steadily up to the end of the Pleistocene, a threefold increase in absolute size over the last three million years. Peak cranial capacities come from the Mesolithic and Upper Palaeolithic (Ruff et al., 1997, Henneberg, 1988), where the mean recorded cranial capacity is regularly over 1500 cc. From this point, the mean cranial capacity fell to the modern worldwide mean of 1353 cc (Beals et al., 1984). This represents a reduction of around 11%,

depending on region. Speculative reasons for decline in brain size over time include stasis between punctuationist leaps (Hofman, 1983), directional selection for smaller body size (Frayer, 1981) and the short term result of low protein consumption in the Holocene (Wiercinzki, 1979 in Henneberg, 1988).

Whilst most studies evaluate the populations in Europe and of European descent (Frayer, 1980, Henneberg, 1992), similar trends are well documented in other parts of the world. Brown (1987) identifies a reduction in the size of the orofacial skeleton, cranial vault and dentition in Australian natives between 13,000 and 5000-6000 years ago. During this period, teeth become smaller, faces become shorter, and the frontal and zygomatic become less robust. Data from Sri Lanka (Kennedy et al., 1987), Nubia (Mulhern and Van Gerven, 1997) and the Mediterranean (LeBlanc and Black, 1974) show the same declines, although at slightly different rates. In the Mediterranean, LeBlanc and Black demonstrated rates of reduction of 2% per 1000 years in maxillary teeth, and 1% per 1000 years in mandibular teeth.

Brain size in modern humans varies from 1,070 to 1,651 cm^3 (Beals et al., 1984), but some of the variation is explained by body size. The measure of brain size relative to body size is the encephalisation quotient (EQ), which reflects the degree of divergence from the brain/body relationship predicted by allometry. The variable used for body size in the calculation of this ratio is body mass, either as directly measured, or calculated from a suitable skeletal proxy such as femoral head diameter or bi-iliac breadth.

Examining the distribution of cranial size around the world reveals larger cranial modules in Northern Eurasia, Australasia and North and East America, smaller modules in Africa, India, Western USA and the central Americas (Reinbold et al., 1985). Cranial module is less variable than body size, because of allometric considerations making crania appear relatively large, even if bodies are smaller. The global range for cranial module is only between 14.2 and 15.5, and is a poor predictor of racial affinity or relatedness.

Studied across this geographical space, brain size reflects climatic conditions, through mediation by vault shape. The head shape is claimed to be more globular in colder climates, to reduce heat loss relative to volume (Beals et al., 1984). Heads can remain roughly the same size, but have larger volumes as a simple result of rounding, which implies that brachycephalisation runs along with encephalisation (Henneberg, 1988). However, studied within a population, brain size may simply reflect body size, at least in part.

Hernandez and colleagues (1997) explain both the extreme size and robusticity of Fuegian crania as the result of the cold, harsh climate and high masticatory stress. They show that the facial features they refer to may have arisen fast, in less than 10,000 years, to become most similar to Arctic populations, despite the distance between them. This is contradicted by Rothammer & Silva (1990) who found that founder effect and geographic isolation in South American prehistoric populations explained much more of cranial shape variation than climate or altitude. This

indicates that cranial shape appears to have a heritable component, even if cranial size may be more associated with climatic factors.

Indeed, the pattern of craniometric variation across human populations matches the pattern of genetic variation (Relethford, 2002), whereas the pattern of skin coloration does not. For both craniometrics and genetic traits, the vast majority of variation is found within groups rather than between groups (87% within groups versus 13% between groups for craniometrics). Relethford argues that the best explanation for this pattern is that of neutral traits under an isolation by distance model. In other words, craniometric variation is selectively neutral overall, and genetic similarity decreases exponentially as distance increases. This model produces average heritability estimates for craniometrics between 0.4 and 1.0.

Within the neutral isolation by distance model there is still the potential for selection to operate on single traits, the effect of which would be obscured by multivariate assessment of the whole skull. Alternatively, it is possible that selection could act on several craniometric traits at once, mediated by a general effect on size or cranial shape (Lahr and Wright, 1996). As with the postcranial skeleton, rugosity and robusticity expression in the cranium are likely to be influenced by size and shape.

The cranial skeleton is genetically and developmentally far more complex than the rest of the skeleton. The molecular mechanisms guiding bone and cartilage formation are different for the cranium and postcranial skeleton, and the cranial skeleton itself is composed of tissues from numerous lineages, including the cranial

neural crest and mesoderm (Helms and Schneider, 2003). As a result, it may well be unrealistic to expect robusticity and rugosity in the cranium and postcranial skeleton to respond in the same way to external forces. However, it is theoretically appropriate to treat them in the same way until this matter is resolved.

Postcranial variation

Body mass and stature during the Pleistocene and Holocene have declined in a similar way to cranial size (Frayer, 1981). Pleistocene humans were 9.2% larger on average than modern people (Ruff et al., 1997). However, very recent modern people in some high-latitude regions have shown a small rise in body size attributed to improved health and nutrition (Bogin, 1999). Without this recent secular trend, the decrease in body mass might well have matched brain size decrease more closely. Despite this, it is clear that the Holocene has been characterised by an overall size reduction in modern humans. A recent study of long bone lengths (Formicola and Giannecchini, 1999) found that stature had decreased across Europe during the Upper Palaeolithic. In Western Europe, the decrease continued throughout the Mesolithic, while the Eastern European populations remained taller.

As a result, encephalisation quotients increased throughout the Pleistocene, and have levelled off during the Holocene. Famously, estimates of Neanderthal brain size are as large or larger than many modern humans, but their larger body mass produces a lower EQ for Late Archaics as a group (Ruff et al., 1997). Alongside this, decreasing diaphyseal robusticity occurs throughout the Pleistocene, but most significantly in the period after brain increase stalled. Ruff et al., (1993) showed an 'almost log-linear decline in femoral shaft robusticity from early Pleistocene to Recent humans'. Cortical area of the femoral midshaft declines in this period from around 675 to 475 mm^2. More recently though, femora from Near East Archaic and Modern

Humans have been shown to be similarly robust, once body proportion differences were taken into account (Trinkaus and Ruff, 1999).

A decline in diaphyseal robusticity has also been reported for the upper limb. Upper Palaeolithic people have been shown to be less robust than Late Archaic Humans, and less robust than foraging recent humans, both in terms of their cross-sections and articular robusticity. However, the Upper Palaeolithic people are more robust than modern agricultural and industrial populations (Churchill, 1999a). The robusticity changes through this time derive both from reduction in percent cortical area and the expansion of both medullary and periosteal dimensions.

The trend towards reduced diaphyseal robusticity is significant through the genus *Homo,* and continues within recent *Homo sapiens.* The causes of the trend might therefore differ at different periods in time. High levels of hypertrophy in the upper and lower limbs of Central European Upper Palaeolithic peoples may have been caused by the carrying or dragging heavy loads for long distances (Trinkaus et al., 2001). However, the finding of lower rates of Haversian remodelling in the Pleistocene compared to modern humans makes discussion of habitual loading in prehistory inconclusive (Abbott et al., 1996).

Variation in activity patterns and loading has been invoked as the main reason for robusticity diversity in recent human populations. Collier shows clear differences in robusticity patterning between two prehistoric Australian populations based on subsistence (Collier, 1989). Similar studies have supported this work in West Coast America (Ruff, 1987, Larsen, 1995, Ruff and Hayes, 1983b), the Khoisan of Africa

(Churchill and Morris, 1998), different kinds of foragers, (Stock and Pfeiffer, 2001) and fishing and non-fishing populations (Weiss, 2003, Berget and Churchill, 1994). Although activity differences are a plausible reason for robusticity change, where subsistence change is also involved, we cannot be sure whether nutrition or activity are the primary causes.

Body proportions in the genus *Homo* have also changed through time, at least in the European populations (Jacobs, 1985). Neanderthals follow Bergman's and Allen's ecological 'rules' in having broad torsos and shortened distal limbs (Trinkaus, 1997). Upper Palaeolithic modern humans appear to be less cold adapted, as they have brachial, crural and claviculo-radial indices that are more associated with tropical populations. By the Mesolithic, the body shape indices of modern humans in Europe have become more cold adapted, although not so extreme as the Neanderthals (Holliday, 1996, 1997). These findings are interpreted as evidence for population migration, followed by adaptation to local conditions. For the Neanderthals in Europe, a combination of robusticity and body proportions have been used to assess changes in activity from the Mousterian to Châtelperronian industry on the basis of loading regime (Trinkaus and Ruff, 1999).

Climate has been invoked as an explanation for modern human morphological variation. Ruff's cylinder model of human body form shows a strong ecogeographic effect on body linearity mediated by thermoregulation (Ruff, 1991, 1994). However, climate and body proportions must also be evaluated carefully. Using latitude as a simple proxy for climate is not always appropriate, since it fails to take into account the local conditions. Coastal peoples, even in tropical locations with warm air

temperatures, may have a 'cold-adapted' physique if prolonged immersion in sea water produces cold stress (Houghton, 1991). Also, simple allometry and scaling may produce body shapes that appear climatically adapted, but are not (Shea and Bailey, 1996).

Differences in diaphyseal circularity between Archaic and Modern humans are also used to infer activity patterns (Lovejoy and Trinkaus, 1980) and determine species affinities (Lovejoy et al., 1976, Kennedy, 1985). However, levels of sexual dimorphism in size and robusticity for Neanderthals have been shown to be the same as in modern humans (Trinkaus, 1980). This has important implications for determining either mating system or sex differences in activity pattern for Neanderthals.

Some skeletal variables appear to be inherently more heritable than others. Stature has been shown to be highly heritable (Little and Malina, 1986). Ruff and colleagues have argued that articulations are less subject to environmental influences than diaphyses, due to functional limitations on the amount of bone remodelling that can take place (Ruff et al., 1991, Ruff et al., 1993). Body proportions may also be heritable, as suggested by Holliday (1997) for the Neanderthals. They are certainly influenced by genetics in modern humans (Livshits et al., 2002).

Whether humans adapt genetically to new environments or individuals respond physiologically, there is a time lag between arrival in new situations and the assumption of a stable phenotype. This phenomenon has been used for investigating

population histories and dispersals. Beals and colleagues (1984), use the relationship between cranial shape and climate to construct clinal maps of cranial shape throughout the Pleistocene. Holliday (1997) uses changes in body proportions as evidence for gene flow and population dispersals in the Late Pleistocene. Issues of body proportion and robusticity are of crucial importance in the debate over the Lapedo child (Duarte et al., 1999, Tattersall and Schwartz, 1999), and indeed in recent attempts to test the Multiregional and Single Origin Models of Modern Human Origins using cranial features (Lahr, 1994, 1996, Lahr and Wright, 1996).

Much of the data reviewed above is not directly comparable, and the rates and timing of the declines vary, but it is clear that Holocene humans have decreased in size throughout the body. One of the effects of these trends would be that recent modern humans are more similar to their modern contemporaries elsewhere in the world than their direct ancestors in their own regions would have been to their own contemporaries. Nonetheless, humans are still a morphologically variable species. The important factors are that single morphological variables can say nothing conclusive about human geographical affinities (Lahr, 1994), and that morphological variation is larger within groups than between groups. Henneberg (1992) values body mass within group variation at 53.4% and between group variation at 29.1%, while sex accounts for 17.5%.

Summary

This thesis explores some of the influences on the human skeleton, an area of study with a considerable history and literature, as reviewed briefly above. The main influences that demand investigation are demographic and epigenetic, within the context of general body size and shape. Age and sex differences in skeletal morphology are examined, as are activity differences, through the impact of subsistence strategy. Climate has been suggested to have impact on a number of skeletal features, and is thus included here. Finally, the genetic influences on skeletal morphology are approached through the study of differences between continents, as an attempt to access information about ethnic heritage.

Defined as above, robusticity and rugosity may reflect different kinds of stress on the skeleton. To establish whether this is the case, the main thrust of this project is to evaluate diversity and patterning in the robusticity and rugosity of modern humans. The literature offers a variety of influences on both robusticity and rugosity, and the secondary thrust of this study is to assess the relative importance of these influences. The findings lead to an analysis of whether the patterning of robusticity and rugosity can distinguish different populations from one another.

The questions explored here take inspiration from, and have implications for, a number of diverse fields in biological anthropology. Sports and physiological sciences are often concerned with the effects of exercise on the body, and with which components of activity have greatest impact on morphology, for people of

different sex, age and population. Rarely do studies in this field have access to a large cross-cultural study group. The same is true for osteoarchaeology; analyses of the extent to which the features of bone can be informative about subsistence regime or activity patterns in individuals or populations usually focus on localised studies. In evolutionary studies, any information to elucidate the causes and implications of differences between Archaic and Modern Human morphology is highly valuable. Understanding skeletal plasticity and response to stress is also vital for determining appropriate characters for phylogenetic study, and for defining species.

For all these fields, a wider test of the basic assumptions about robusticity and rugosity is timely and useful. This thesis is a novel contribution in that it uses both metric and non-metric assessments of robusticity and rugosity across the crania and postcrania. These variables are examined in a large, geographically and ethnically diverse modern human data set. The aims and hypotheses of the study are laid out below.

Aims

1. To explore and describe modern human diversity in robusticity and rugosity.
2. To examine the influence of age and sex on rugosity and robusticity.
3. To examine the influence of climate, lifestyle and continent on rugosity and robusticity.
4. To examine the influence of body size and shape on rugosity and robusticity.
5. To see whether robusticity and rugosity correlate within individuals and populations.
6. To see whether cranial and postcranial assessments of robusticity and rugosity correlate.

The null hypotheses are that there are no statistically significant influences on robusticity and rugosity in the modern human skeleton from age, sex, climate, lifestyle, continent, body size or body proportions. In essence however, previous literature would lead to the expectation that any of these null hypotheses could be proven to be false, and suggest how robusticity and rugosity levels and patterns might be expected to respond to these influences. Older, larger persons might under any circumstances be found to be more robust and rugged than younger or smaller people; males are likely to be found to be more rugged and robust than females. Lifestyles that produce rigorous stresses on the skeleton may be associated with more rugged or robust skeletal elements, which may be those requiring considerable weight-bearing, long-distance mobility, or large ranges of movement at certain joints.

Climatic and continent influences may be felt through their relationship with body proportions and with local genetic selection (or drift) for certain morphologies.

Further null hypotheses are that robusticity and rugosity levels are patterned randomly across the body, and do not correlate or covary with each other. These also are likely to be falsified, but there are interesting implications with falsification, or indeed the support of the null hypotheses.

If the data sets for robusticity and rugosity correlate, both as patterns in the same individuals and across the same populations, then we may assume that robusticity indices and musculoskeletal markers are accessing the same basic data about the skeleton. Both forms of remodelling are therefore likely to be triggered by the same biomechanical and endocrine experiences. In this situation, a systemic effect on bone remodelling cannot be identified. However, its existence cannot be disproved, since this study looks exclusively at surface features of human bone, and not at cross-sectional cortical properties.

If robusticity and rugosity are not correlated with each other, then we may conclude that two different stimuli and response systems have been accessed. Alternatively, either robusticity or rugosity may be more heritable than the other variable, or more susceptible to error or random effects. Both robusticity and rugosity are measured in similar places on the same skeleton, which is a functional and highly interconnected system. Thus, some degree of correlation between the two data sets is to be expected.

Even with direct correlation between rugosity and robusticity, MSMs may still be informative, since they may allow the observer to pinpoint more accurately the nature or directions of strain experienced. MSMs may highlight the muscle groups most stressed or active in an individual, which have been most influential in producing the diaphyseal robusticity observed. Furthermore, MSMs may allow characteristic activity patterns of people in that community to be determined, as long as a large sample is used. Finally, if MSMs and external measurements coincide, then they may be used interchangeably when assessing partial skeletons and broken elements in archaeological or forensic studies.

These hypotheses, aims and their implications are revisited in Chapter 8, and discussed in the light of the project findings.

Chapter 2 : Methods and Materials

Introduction

The research questions outlined previously require the collection of external measurements of size and shape of various long bones and the skull, as well as assessments of the morphology of surface features on these elements. Essentially, there are four kinds of data, where different methodological approaches are necessary. These are, postcranial metric data, including indices, postcranial scored data, cranial metric data and cranial scored data (PM, PS, CM and CS). Each kind of data is explored in a preliminary investigation, described below and presented in chapters 3 to 6.

The aims of the preliminary investigations are to explore the extent to which variation in the data can be attributed to age, sex or population characteristics such as subsistence ecology, local climate, and continent. This allows the production of typical profiles and trends for each of the populations, compiled by examining a few key questions at a time. These general patterns are used to interpret the results of subsequent larger analyses, presented in chapter 7, which incorporate more of the different data types in order to establish the extent to which the different data types correlate in describing the populations.

Methodological issues arising out of sample selection, calculation of error rates and missing data are discussed first, followed by descriptions of the variables used in this

study. These variables are then investigated for normality of distribution, and violations of normality are discussed. Finally, I present descriptions of the populations included in the data set, along with an explanation of the way in which they have been categorised into sub-populations for the analyses that follow.

Methodological Issues

Sample selection

All data were collected for each individual, as far as possible. Individuals selected for the sample have well associated cranial and postcranial material, in reasonably good condition. All show full closure of limb epiphyses to indicate adulthood. Individuals were excluded if they showed signs of pathology likely to affect bone morphology or activity levels, such as osteitis, Paget's disease, or severe osteoarthritis. In the case of the Terry Collection, individuals known to have suffered fatal diseases that were likely to have resulted in prolonged terminal immobility were excluded. Limbs where any element showed signs of trauma were excluded from the database, since activity levels in that limb could be assumed to have been reduced.

Missing data

The perennial problem of missing data was treated in several ways. For all bilateral measurements, a mean was taken of left and right sides. This compensates for missing or damaged elements better than simply using elements of one side, and means that more data can be collected. If there is only a left element present for a given individual, and the rest of the database uses right sides only, then using the dimensions of the left element could be introducing significant error, especially in an element typically asymmetrical such as the humerus.

Alternatively, if both elements are present for an individual, the dimensions for each element are closer to the mean dimensions for that individual than they are to each other. In other words, by using mean values wherever both left and right elements are present, the dimensions of the occasional single element differ less from the theoretical mean of both elements for that individual, than they would differ from the dimensions of their missing opposite. In a data set where missing data is a problem, using this technique is advantageous.

Missing variables were filled using sex and population specific expectation maximisation (EM) (Tabachick and Fidell, 2001). Expectation maximisation is a two-stage, iterative, maximum likelihood method for estimating missing data. The expectation step generates a conservative distribution for the missing values, and the maximisation step improves the distribution to converge towards the existing distribution. This is repeated until the parameters for the estimated data match the

existing data (McLachlan and Krishnan, 1997). EM methods are better than using regression for filling missing values, because they avoid impossible matrices, produce realistic estimates of variance, and avoid over-fitting. Where regression is used to fill data for principle components analysis, for example, it may create spurious factors (Tabachick and Fidell, 2001).

The process of filling missing data was only carried out for variables where several other closely related measurements from that bone were available. No more than two variables for each bone have been filled in this manner, and in no cases were both length and diameter data estimated. Different analyses required different variables, so individuals excluded from one may be included in others. The actual sample size for each analysis is reported with the results.

Error analysis

The metric and scored variables used were selected following pilot work to ensure utility in these analyses and an error rate under 2%. Variables with higher error were excluded. The pilot study, presented in part in Imber and Aiello (2001), consisted of assembling a diverse global sample of individuals on which to test the metric variables and develop the postcranial scoring system. Using this diverse sample, including individuals from all continents and many different lifeways, meant that the scoring system was developed with access to the full range of human diversity. This ensures that the range of variation in each (MSM) is properly partitioned, and the extremes are not collapsed into single score grades. Only those variables with high

repeatability (low intra-observer error) across the pilot sample are included in the current study.

Inter-observer error calculation was possible for the cranial scored variables, using repeated blind measures. I use the cranial scoring method developed by Lahr(1994, 1996), and I also use some of the same individuals used in her analyses. Investigation of inter-observer error on these individuals was used to refine my own scoring technique to produce comparable results to those of Lahr, and results are thus not reported here.

For those collections that were only visited once, 20% of the individuals were entirely re-assessed, at the end of the data collection period. Over 40% of the material from the Smithsonian Museum and the Duckworth Laboratory was re-assessed a year after the initial data collection period. All of the material from the Natural History Museum was re-assessed once, and much of it twice, at least six months after the previous measurement. Intra-observer error rates for metric variables are calculated following White and Folkens (2000), and are reported below with the descriptions of the variables. Error rate for scored variables is the likelihood that a different score would be obtained on repeated assessment. In no cases were repeated scores ever different by more than one grade.

Software and Statistical Issues

The complete data set was compiled in Microsoft Excel 95 version 7.5 (Microsoft Corp., 1997), and analysed using SPSS version 10 (SPSS Inc. 1999). There are some important limitations to the statistical analysis of data produced by scoring rather than measurement. There is no equivalence between the same score produced at different sites on the skeleton. The score only reflects the position relative to the rest of the population that an individual has at that site. Selecting statistical techniques that can handle both scored and metric data in this scenario is difficult. The methods utilised here are imperfect, in that in some occasions alternatives might be more appropriate. However, in order to reduce the complexity of discussion, and to provide a clearer comparison between analyses, the techniques described below have been applied across the board. Instances where alternative methods might be useful are noted below.

The variables are examined using the categories of age, sex, climatic region, lifestyle (subsistence regime) and continent, as well as between the populations themselves. The descriptive statistics for each of the four kinds of data are presented with the results. Principal components analyses are used to summarise the variability in each of the four data types to a limited number of informative factors. Skewness, kurtosis, missing values and lack of linearity between pairs of variables are significant problems for PCA, but where it is used simply to describe and summarise the relationships in a large set of observed variables, these assumptions are less critical (Tabachnick and Fidell, 2001). Thus, PCA can be used on scored data in most

cases, even though it is designed for interval data. Variables where these assumptions are violated are discussed below. An alternative method for scored data would be Multiple Correspondence Analysis.

The means and variance of the variables are examined using the categories of age, sex, climatic region, lifestyle (subsistence regime) and continent, as well as between the populations themselves. The four kinds of data are examined for normality, and explored initially using one-way ANOVA or the non-parametric equivalent Kruskal-Wallis test. Appropriate post hoc tests are used for ANOVA, on the results of a Levene test for homogeneity of variance. If equal variance can be assumed, a Tukey HSD test is used, whereas Tamhane's T2 test is used where one cannot assume equal variance. Both of these tests allow all pairwise comparisons of means (Tabachnick and Fidell, 2001), to highlight Type I errors where the basic one-way ANOVA finds chance differences to be significant.

The Kruskal-Wallis test does not have an equivalent to post-hoc testing, but does itself test all pairwise permutations directly. This means that both post-hoc tests on ANOVA and the Kruskal-Wallis test can show where the key differences between sub-categories lie. For example, a one-way ANOVA may show that a variable is significantly different between climates, but the post-hoc test may pinpoint that difference as being significant only between hot and cold climates, rather than between temperate and other climates. Investigating the subtle differences between sub-categories is the main reason to use the one-way ANOVA and Kruskal-Wallis tests, since otherwise they are biased by the makeup of the sub-categories.

Multi-way ANOVA is a more rigorous way of modelling the real world than one-way tests, since all the potential influences on skeletal size, shape, robusticity and rugosity discussed in Chapter 1, are incorporated. Each potential influence can be controlled while the relative importance of the other influences can be established. This method reduces the possible bias from uneven distribution of individuals into demographic, lifestyle and eco-geographic sub-categories, which is necessary in a study of this design. An experimental study where all spaces in the sub-category matrix were evenly filled would not suffer the same problem, but in a comparative study using real human populations, precautions must be taken to avoid bias.

Multi-way ANOVA with interactions compares the variance for each of the variables in the full data set with that remaining when one of the five categories (age, sex, climate, lifestyle, continent) is removed. If a significant difference is found between the variance including that category and the variance when the category is removed, then it follows that that category has a significant effect on that variable. Importantly, multi-way ANOVA allows each category to be investigated in turn, while holding the other categories constant.

Using multi-way ANOVA also allows interactions between the categories to be assessed. A significant interaction between two or more categories simply implies that variance in one category (for that variable) is non-random with respect to variance in another category. An example might be a significant interaction between age and sex on a size variable. This can be interpreted as showing that males and females grow at different rates. This method also provides an opportunity to test

hypotheses about the explanatory power of each factor, such as whether climate is more or less influential than sex. To do this would require designing models containing assumptions about the relationships between the categories. This is not reported here, and is a logical extension of this study. It is perhaps likely that the demographic factors (age and sex) should interact differently than the environmental factors (climate and lifestyle). However, in the first instance, a straightforward analysis making no such assumptions is most useful.

Population profiles are produced to summarise how each of the major ethnic groups in the data set relate to the rest in the way in which the four data types characterise them. The comparison of the four data types (Postcranial Metric, Postcranial Scored, Cranial Metric, Cranial Scored) is carried out using least-squares linear regression and discriminant function analysis. Regression analysis is used to establish whether there is a linear relationship between the variables, and to determine the strength of that relationship.

For some comparisons between rugosity and robusticity, such as the linear regression analysis, aggregated z-scores have been produced, following the method advocated by Weiss (2001, 2003 a,b). This has the benefit of increasing reliability and statistical strength of the results, but reduces the localised descriptive quality of each muscle score. Scores are aggregated on the basis of functional muscle complexes in particular body regions, which is supported by the results of principle components analysis to establish how the separate scores group on distinct components.

In discriminant function analysis, each data type is used in turn to sort the data set into sub-groups. These are compared to identify where they agree and differ, and which individuals and populations are most subject to mis-identification. Data types that produce very different sorting patterns cannot be reflecting the same underlying information, and so disparity between the sorting patterns is evidence that the four data types are not equivalent. Agreement between the sorting patterns is evidence that the data types are positively correlated.

The discriminant function analysis (DFA) is a logical extension of multivariate ANOVA, simply turning the focus from evaluating how group membership is associated with mean differences in dependent variables, to using combinations of variables to produce predictions about group membership. With DFA one can also assess the accuracy of prediction. DFA has no special problems with unequal sample sizes in the data set (Tabachnick and Fidell, 2001), however, the smallest group size must be larger than the number of predictor variables, so small groups are removed from this analysis, and only individuals with no missing values from the major, homogenous populations are used. This produces a reduced data set, but also provides the fairest comparison between the data types.

Distribution of Variables

The variables were examined for normality of distribution using statistical and observational methods. All the postcranial metric variables and indices are normally distributed and are treated as such in parametric statistical tests. As the sample sizes for each variable are well over 200, the impact of departure from zero kurtosis or skewness in either direction is considerably reduced, and both skewness and kurtosis levels are low for all variables.

The postcranial scores also approach normality when viewed graphically, but the Kolmogorov-Smirnov test (with Lilliefors significance correction) reveals all scored variables to be significantly differently distributed from normal. Some variables are significantly skewed, since the scoring system, although developed to reflect the full range of human rugosity diversity, can only reflect the rugosity levels in the populations sampled. However, both Principal Components Analysis (PCA) and Discriminant Function Analysis (DFA) can be used on this data type. PCA is being used in this study only for descriptive purposes rather than for producing definitive results. DFA is resistant to failures of normality deriving from skewness, particularly where the degrees of freedom can be reduced (Tabachnick and Fidell, 2001).

The cranial metric variables conform closely to normality, showing little kurtosis or skew, both statistically and graphically. The cranial scored variables do not conform to normal distributions, mainly since there are fewer scores available for each variable than the five allowed in the postcranial scores. Also, some of the variables have extreme conditions that are rare among the global population sampled. PCA

and DFA are used on this data type in order to compare it to the other data types, although the results are interpreted conservatively, and the preliminary investigation of these variables are restricted to non-parametric methods.

Postcranial metric variables

For the postcranial skeleton, measurements focus on the major long bones and clavicle, particularly their length, external diaphysis dimensions and joint surface dimensions. Standard metric measurements of the skeleton are used following Martin (1928), and those variables used in this study are listed below (Table 2.1). They are used primarily in the construction of indices of diaphyseal robusticity, epiphyseal robusticity, diaphyseal circularity, and body proportions.

Variation in human postcranial robusticity, body shape and proportions has traditionally been investigated using indices (Pearson, 2000, Lovejoy et al., 1976, Collier, 1989, 1993). In this context, the use of indices provides a simple method of size correction, since they are simply measurements of some pertinent feature, size corrected using a relevant element length.

Index formulae

All Robusticity Indices (RI) are calculated in the same way, using the mean of anterior-posterior and medio-lateral diameters (at midshaft or some other selected

point along the diaphysis), divided by element functional length. This method follows Pearson (2000), and the formulae are listed below (Table 2.2).

Table 2.1 : Postcranial variables

Variable	Code	Error (%)	Martin code
Femur functional length	FFXL	0.338	11.2
Femur midshaft anterior-posterior diameter	FMSAP	0.457	11.7
Femur midshaft medio-lateral diameter	FMSML	0.464	11.8
Femur sub-trochanter anterior-posterior diameter	FSTAP	0.431	11.10
Femur sub-trochanter medio-lateral diameter	FSTML	0.477	11.9
Femoral head cranial-caudal diameter	FHD	0.465	11.18
Femur lateral condyle length	FLCL	0.675	11.22
Femur distal articulation breadth	FDAB	0.228	11.21
Tibia functional length	TFXL	0.162	13.2
Tibia midshaft anterior-posterior diameter	TMSAP	0.379	13.8
Tibia midshaft medio-lateral diameter	TMSML	0.669	13.9
Tibia plateau anterior-posterior width	TPAP	0.385	13.4
Tibia plateau medio-lateral width	TPML	0.144	13.3
Ulna functional length	UFXL	0.750	8.2
Ulna midshaft anterior-posterior diameter	UMSAP	1.025	8.11
Ulna midshaft medio-lateral diameter	UMSML	0.807	8.12
Ulna sub-brachiator anterior-posterior diameter	USBAP	1.898	8.13
Ulna sub-brachiator medio-lateral diameter	USBML	1.785	8.14
Ulna distal articulation maximum diameter	UDAMX	0.688	8.9
Clavicle maximum length	CMXL	0.846	4.1
Clavicle maximum midshaft diameter	CMSMX	1.143	4.6
Clavicle minimum midshaft diameter	CMSMN	1.942	4.5
Radius functional length	RFXL	0.519	7.2
Radius midshaft anterior-posterior diameter	RMSAP	0.927	7.4a
Radius midshaft medio-lateral diameter	RMSML	1.611	7.5a
Radial head maximum diameter	RHDIA	0.260	7.4 (1)
Radius distal articulation total breadth	RDATB	0.311	7.6a
Humerus functional length	HFXL	0.283	6.2
Humerus midshaft anterior-posterior diameter	HMSAP	1.395	6.6b
Humerus midshaft medio-lateral diameter	HMSML	0.206	6.6c
Humerus deltoid anterior-posterior diameter	HDEAP	1.274	6.5
Humerus deltoid medio-lateral diameter	HDEML	0.354	6.6a
Humerus distal articular breadth	HDAB	0.957	6.11
Humerus head total anterior-posterior diameter	HTHB	0.759	6.9
Humerus head cranial-caudal diameter	HHDIA	0.553	6.10

Diaphyseal circularity indices (CI) are all calculated as the medio-lateral diameter divided by the anterior-posterior diameter. The closer the index is to 1, the more circular the diaphysis cross section. Indices over 1 show the bone to be thicker in the medio-lateral plane, indices under 1 show the bone to be thicker in the anterior-posterior plane. The indices of circularity, such as the tibia cnemic index (TMSFI) as used by Lovejoy et al. (1976) are reported to reflect habitual directions of force on the diaphysis. The plane in which the diaphysis is thickest is assumed to be the plane in which force is greatest.

Articular surface robusticity indices (JI) are produced by producing an estimate of articular surface area, and dividing by the relevant element length. They have been used to advantage by a number of researchers (Collier, 1989, 1993, Pearson, 2000), since they reflect body mass at the attainment of adulthood. However, the epiphyses appear not to respond biomechanically to further changes in body mass or activity throughout later life, as the diaphyseal dimensions have been shown to do (Holliday, 1999). As such, comparisons between articular surface robusticity indices and diaphyseal robusticity indices may be useful in establishing the degree to which activity patterns affect robusticity (Pearson, 2000).

Indices of body proportions have also been used successfully in several contexts, tracing population movements and adaptation to climate (Holliday, 1996, 1999, Holliday and Ruff, 2001, Zacrzewski, 2003). Distal limbs have been shown to be shorter and torsos relatively wider in colder climates as adaptations to reduce heat loss through the skin. This body shape has also been shown to be heritable

(Holliday, 1996), since several generations are necessary for populations newly immigrant to cold climates to develop the wider body shape with shorter distal limbs. The brachial and crural indices assess the relative length of proximal and distal elements in each limb, while the claviculo-radial index assesses the relative torso width for radius length. The formulae for these indices are listed below (Table 2.2).

Table 2.2 : Postcranial index formulae

Category	Index	Code	Formula	Reference
Body shape	**Brachial**	BI	BI = (humerus functional length/radius functional length)*100	Holliday, 1996
	Crural	CI	CI = (femur functional length/tibia functional length)*100	Holliday, 1996
	Claviculo-radial	CRI	CRI = (clavicle functional length/radius functional length)*100	Holliday, 1996
Robusticity	**Femur midshaft**	FMSRI	(Femur midshaft mean diameter / Femur functional length)*100	Ruff, 1994
	Femur sub-trochanter	FSTRI	(Femur sub-trochanter mean diameter / Femur functional length)*100	Ruff, 1994
	Tibia midshaft	TMSRI	(Tibia midshaft mean diameter / Tibia functional length)*100	Ruff, 1994
	Humerus midshaft	HMSRI	(Humerus midshaft mean diameter / Humerus functional length)*100	Ruff, 1994
	Radial midshaft	RMSRI	(Radial midshaft mean diameter / Radial functional length)*100	Ruff, 1994
	Ulna midshaft	UMSRI	(Ulna midshaft mean diameter / Ulna functional length)*100	Ruff, 1994
	Ulna sub-brachial	USBRI	(Ulna sub-brachial mean diameter / Ulna functional length)*100	Ruff, 1994
	Clavicle midshaft	CMSRI	(Clavicle midshaft mean diameter / Clavicle functional length)*100	Ruff, 1994
Circularity	**Femur midshaft**	FMSFI	Femur midshaft mediolateral diameter / Femur midshaft anterior-posterior diameter	
	Femur sub-trochanter	FSTFI	Femur sub-trochanter mediolateral diameter / Femur sub-trochanter anterior-posterior diameter	
	Tibia midshaft	TMSFI	Tibia midshaft mediolateral diameter / Tibia midshaft anterior-posterior diameter	Lovejoy, et al. 1976
	Humerus midshaft	HMSFI	Humerus midshaft mediolateral diameter / Humerus midshaft anterior-posterior diameter	
	Radial midshaft	RMSFI	Radial midshaft mediolateral diameter / Radial midshaft anterior-	

			posterior diameter	
	Ulna midshaft	UMSFI	Ulna midshaft mediolateral diameter / Ulna midshaft anterior-posterior diameter	
	Ulna sub-brachial	USBFI	Ulna sub-brachial mediolateral diameter / Ulna sub-brachial anterior-posterior diameter	
	Clavicle midshaft	CMSFI	Clavicle midshaft mediolateral diameter / Clavicle midshaft anterior-posterior diameter	
Articular	**Tibia plateau**	TPFI	((Tibia plateau AP * Tibia plateau ML) / Tibia functional length)*100	Pearson, 2000
surface	**Femur distal**	FDFI	((Femur lateral condyle length * Femur distal articulation ML width) / Femur functional length)*100	Pearson, 2000
	Humerus head	HPFI	((Humerus head cranial-caudal * Humerus head ML) / Humerus functional length)*100	Pearson, 2000
	Radial head	RPFI	(((Radial head diameter/2) 2 Pi) / Radius functional length) *100	Pearson, 2000

Postcranial scored variables

A five-grade scoring system based on that devised by Hawkey (1988) is used to assess musculoskeletal stress markers (MSMs) in selected regions of the postcranial skeleton. A scoring system is used in preference to the measurement of MSMs for the following reasons. MSMs are difficult to measure, being morphologically complex and highly variable. MSMs do not necessarily have clearly defined edges or landmarks, and their ontogeny is not clearly understood. A five-grade categorisation has been used successfully and objectively in this context before (Hawkey and Merbs, 1995, Miles, 1999, Robb, 1998, Weiss, 2001, 2003 a,b), and is useful because it is a straightforward technique, easily transferable to a variety of body locations. Low intra- and inter-observer error rates have been demonstrated (Hawkey, 1988, Hawkey and Street, 1992). The descriptive criteria for each score are listed below (Table 2.3) with a description of the score site used (Figures 2.1 - 2.14). A selection of the photographs that were used to support these criteria are presented in the Appendix.

The error percentage rate is simply the chance of getting a different score on a repeat assessment of that individual. This is calculated as the number of observations that deviate from the first assessment, divided by the number of observations made, multiplied by 100. As such, error rates are typically higher than for metric data. In no cases was a repeat score more than one grade away from the original score. Where repeated assessments produced different scores, a third assessment was made several months later, and the

majority score accepted. Where grades for the two sides of an individual were different, the mean was taken.

Table 2.3 : Postcranial scored variables.

Score code	Description	Error rate
TTSCO	Tibia tuberosity score	2.381
TSSCO	Tibia popliteal score	4.462
USSCO	Ulna supinator score	2.910
UPSCO	Ulna pronator score	2.604
UBSCO	Ulna brachialis score	2.100
CDSCO	Clavicle distal score	1.939
CSSCO	Clavicle sternal score	2.375
CLSCO	Clavicle sternal lipping score	2.949
RTSCO	Radius tuberosity score	4.396
RHSCO	Radius head lipping score	5.249
HBSCO	Humerus bicuspid groove score	2.381
HDSCO	Humerus deltoid score	2.162
FGSCO	Femur gluteal score	2.872
FPSCO	Femur pilaster score	3.377

A further reason to use scored variables is that, unlike indices, they do not require elements to be substantially complete in order to be useable. Partial elements may still hold a complete muscle attachment site. Since scored data is presumed to be independent of size, the lack of comparable metric variables is not considered to be a problem. However, since this study uses only relatively complete elements, it provides an opportunity to test this size-independence further. Where the score descriptions define MSMs as large or small, this is to be considered relative to the size of the bone.

Some scoring methods consider robusticity hypertrophy and stress lesions (pitting) separately, although admitting that they often form a continuum (Hawkey and Merbs, 1995). The robusticity development is considered normal

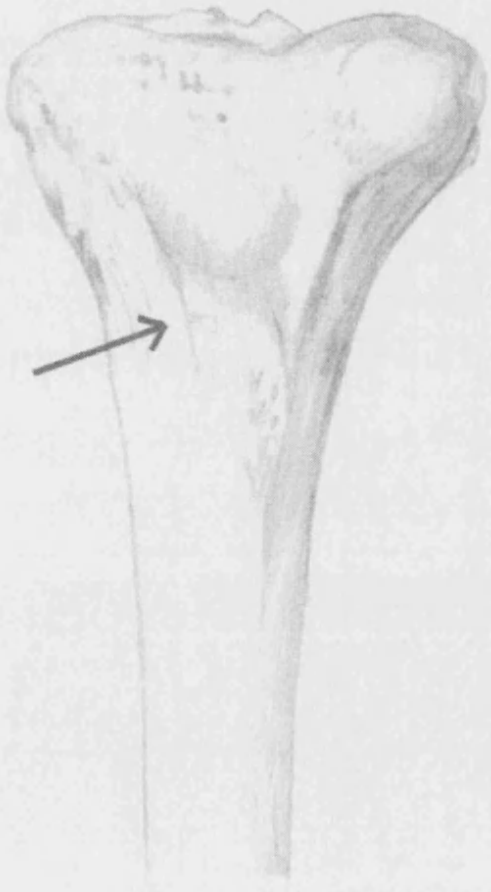
producing rugged markings at MSMs, culminating in extreme ridges or sharp crests of bone. At tendon attachments, it is the immediately surrounding region that develops hypertrophy in response to stress, because the cartilage layer prevents resorption or formation of new bone there.

The stress lesion develops at loading levels beyond that, being pitting or furrowing into the cortex, only found at MSMs. If pits are noted elsewhere, then the lesions cannot be considered to be activity based, but disease based, and so the individual is removed from the database. Hawkey and Merbs therefore work from a 6 grade scale, but noted the frequent overlap of their category 3, meaning high robusticity, and their category 4, meaning stress level 1. In this study, I have conflated their six grades into five, where pitting is only present in the last two.

Score descriptions

Figure 2.1: Tibia tuberosity score : TTSCO

This is the attachment site for the patellar ligament. Stress is exerted via the quadriceps muscles - the major knee extensors (quadriceps femoris comprising vastus medialis, vastus intermedius and vastus lateralis plus rectus femoris) that arise around the femur greater trochanter and ilium.



1: Smooth, slight bulge to cortex

2: Gentle bulge to cortex with mild striations

3: Medium to large protrusion, moderate striations across tuberosity

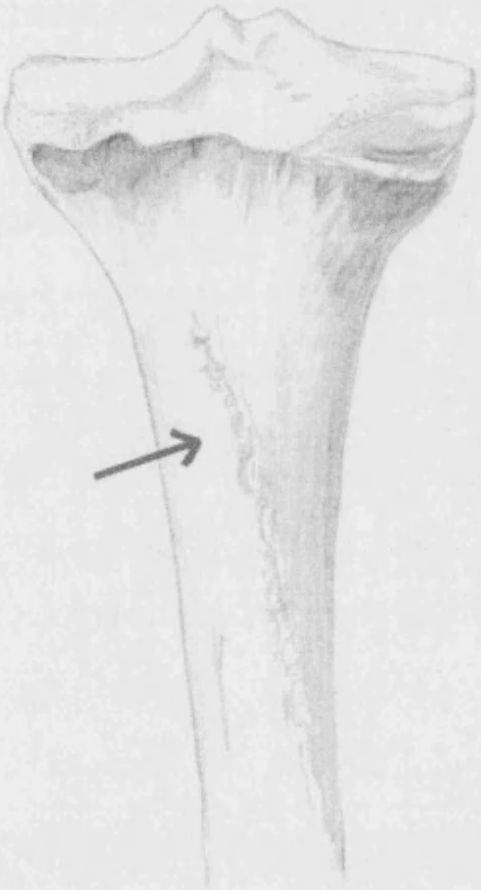
4: Protrusion very distinct from bone surface, moderate striations and shallow lesions distal to tuberosity

5: Very large protrusion from surface, multiple distinct ridges across tuberosity, sharp, uneven crest to distal edge of tuberosity, and moderate lesions beneath it.

Example image: Score 2

Figure 2.2: Tibia soleal score : TSSCO

This is the attachment site for soleus. Other muscles attach nearby (popliteus and tibialis posterior) but do not affect this ridge. Soleus is the plantar flexor of foot at the ankle, and is active in locomotion and squatting postures.



1: Smooth, no sign of line

2: Partial, faint line visible under strong, lateral light

3: Broken line, striated in places,

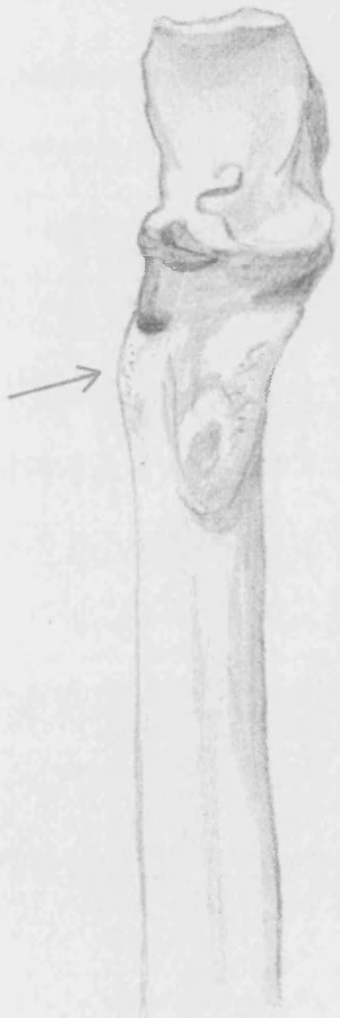
4: Complete line, moderately striated all along, gentle ridge of bone formed along it

5: Complete, extensive line, strongly striated all along, with strong ridge or crest formed along it.

Example image: Score 5

Figure 2.3: Ulna supinator score : USCO

This is the origin for the ulna supinator, a deep muscle on the back of the forearm. Supinator has two heads, arising from the humerus and ulna, which sweep around the radius to attach into the anterior surface of radius. This muscle can supinate in any position of the arm, and is thus extensively used in many situations involving forearm supination.



1: No crest, shallow surface markings only

2: Small, smooth crest or bulge, not extending distally along diaphysis

3: Moderate, rounded crest or bulge with smooth or lightly striated surface, extending distally along diaphysis

4: Moderate crest extending along diaphysis, sharp, angular profile, moderate striations

5: Very prominent crest, sharp, angular profile, strongly striated and of considerable extent along diaphysis

Example image: Score 2

Figure 2.4: Ulna pronator score: UPSCO

This is the origin for pronator quadratus, a deep muscle which pronates the forearm. This muscle is in contact with the interosseous membrane.

1: Entirely smooth, no ridge or line visible

2: Short, gentle line, visible under strong lateral light

3: Gentle, rounded crest extending proximally along diaphysis

4: Moderate, angular crest associated with bulging cortex, extending proximally along diaphysis

5: Strong, angular crest, twisted and striated profile, considerable extent proximally along diaphysis, associated with a strong, hypertrophic 'wing' of bone

Example image: Score 2

Figure 2.5: Ulna brachialis score : UBSCO

This is the attachment for brachialis, a strong but simple flexor of the elbow, implicated in lifting and other arm activity.

1: Smooth, retracted surface under articulation, shallow depression only at attachment site

2: Moderate depression associated with smooth, gently bulging cortex, no pitting or striations

3: Moderate pit across attachment site, rough surface, mild striations and gently bulging cortex surrounding attachment site

4: Moderate pit, moderate hypertrophy beneath attachment site producing a distinct 'step' up from the diaphysis surface, moderate striations and rough surface

5: Large pit or scar, rough surface, extensive hypertrophy producing a pronounced ledge or step on which the attachment is sited, strong striations

Example image: Score 3

Figure 2.6: Clavicle distal ligament score : CDSCO

This score assesses the attachments for the conoid and trapezoid ligaments and the coracoclavicular ligament, which supports the weight of the upper limb. This score reflects stress in terms of wear, since it is a weight-bearing rather than a movement related zone.

1: Smooth, and essentially featureless region, gentle depression only

2: Small, smooth tubercule, with rounded profile, associated with a gentle depression running parallel to diaphysis

3: Moderate, rounded tubercule, with mild hypertrophy on opposite side of depression, mildly striated

4: Moderate tubercule with angular profile, moderate hypertrophy opposite, moderate striations or pitting and moderately deep, extensive depression

5: Double hypertrophic crest and strong, deep depression between them, rough, pitted surface, multiply striated, and 'twisted' look to region

Example image: Score 4

Figure 2.7: Clavicle sternal ligament score: CSSCO

This is the ligament attachment from the costoclavicular ligament to the first rib and manubrium. This sternoclavicular joint resists movement and steadies the clavicle during arm and shoulder movement. The score reflects wear from weight-bearing rather than movement, since it is a ligament attachment.

1: Smooth, shallow depression only

2: No hypertrophy or pitting, but depression is distinct, with defined edges

3: Distinct, edged depression with mild pitting or striation, associated with mild surrounding hypertrophy

4: Moderately deep, defined depression, rough and pitted within, plus moderate hypertrophy extending along diaphysis

5: Strong and deep depression, edges lipped and rough, heavily pitted with deep lesions, strong hypertrophy beneath and around scar, significantly extending along diaphysis

Example image: Score 3

Figure 2.8: Clavicle sternal lipping score: CLSCO

This score reflects osteo-arthritic lipping or build up promoted by wear along the posterior edge of the sternal articulation of the clavicle. The wear derives from weight hanging from the arm, and can be considered 'carrying arthritis'.

1: No lipping, a smooth, angular edge to diaphysis all around

2: Gentle lip with rounded profile, restricted to small region of diaphyseal edge, no obvious hypertrophy associated

3: Moderate lip, with some mild associated hypertrophy, restricted to small region of diaphyseal edge

4: Moderate, smooth profiled lip, extensive along diaphysis edge, associated with moderate hypertrophy and mild pitting, resulting in considerable projection of lip along diaphysis

5: Strong, rough edged lip, extensive along diaphysis edge, associated with strong hypertrophy, strong projection of lip along diaphysis, and pitting beneath and around it

Example image: Score 2

Figure 2.9: Radius tuberosity score : RTSCO

This is the biceps brachii tendon attachment, which is predominantly a strong elbow flexor. Biceps also contributes to supination in flexed positions of the arm.

1: Smooth bone, mild depression on surface, narrower than diaphysis, no surrounding bony margin

2: Smooth, gently bulging surface, no striations or pitting, but gently defined edges to attachment site,

3: Moderate tuberosity, some mild roughness and striations across insertion, clearly defined edges, and mild hypertrophy of surrounding site

4: Moderate tuberosity, moderately striated and pitted with well-defined, crested or lipped edges, associated with hypertrophy producing margins to attachment site

5: Large tuberosity, wider than shaft, with associated hypertrophy producing strong margins or prominence above diaphyseal surface, insertion site has strongly defined and built-up edges, and deep indentation

Example image: Score 3

Figure 2.10: Radial head lipping score: RLSCO

This score reflects wear from the annular ligament, which wraps around the radial head and ulna. Wear here reflects all arthritic changes due to elbow activity.

1: No lip discernible, radial head is of even depth all around rim

2: Radial head has uneven depth, but no striations, roughness or lipping

3: Radial head has uneven depth, but has smooth, rounded profile, but there is a defined and moderately built-up lip to distal edge at tallest part

4: Moderate portion of radial head is of uneven depth: this section has moderate lipping and build-up, associated with undulating, rough and crested radial head circumference

5: Large portion of radial head has uneven depth (c. ¼ circumference), the deep section is bulging, radial head circumference has rough and strongly crested edge, and considerable lipping and build-up: the impression is that the distal edge is swollen

Example image: Score 2

Figure 2.11: Humerus bicipital groove score : HBSCO

This score site, also known as the intertubercular groove, is the position occupied by the tendon of the long head of biceps. The assessment of this site focuses on the attachments for pectoralis major, latissimus dorsi and teres major. Pectoralis major forms the anterior wall of the axilla, while teres major and the tendon of latissimus dorsi form part of the posterior wall. Both pectoralis major and latsissimus dorsi are powerful adductors of the upper limb with additional responsibility in medial rotation of the arm. Teres major has similar functions and also acts to keep the humerus head in the glenoid cavity.

1: Smooth cortex, short, wide and shallow depression, no pitting or striations

2: Gently bulging margins either side of a smooth and wide depression, no striations

3: Moderately bulging, rough attachment site margins, moderately deep depression

4: Moderate hypertrophy producing crest or ridge on one margin, but both sides rough, pitted or striated

5: Strong hypertrophy forming distinct, angular crests/ridges, deep, rough and pitted depressions beside crests

Example image: Score 4

Figure 2.12: Humerus deltoid score : HDSCO

This is the major attachment for the deltoid, a flat multipennate muscle with versatile functions. It can flex and extend the arm, and acts as the chief abductor of the arm at the shoulder joint. It is implicated in upper arm and shoulder activity.

1: Smooth bone, bulge only detectable by touch or under strong lateral light, no striations

2: Mild, smooth bulge associated with gentle, smooth depression

3: Moderate bulge with rounded profile, moderate striations or mild pitting in mild depression

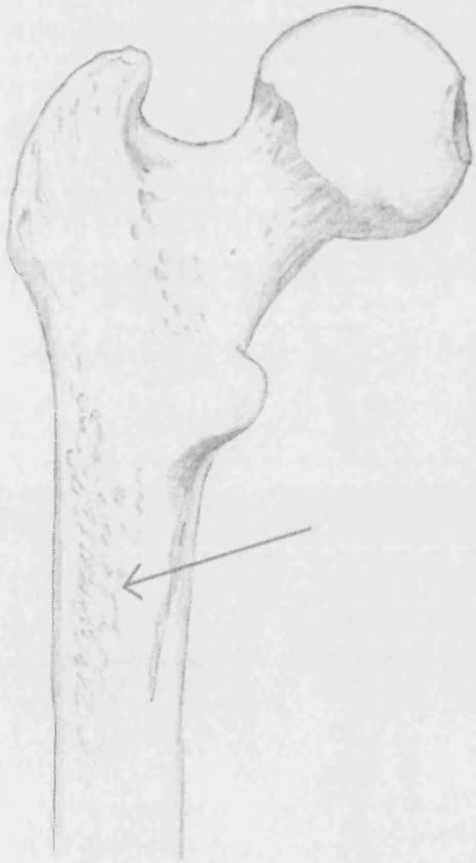
4: Moderate ridge or crest of bone, associated with moderate striations and pitting, and moderate depression

5: Strongly angular and hypertrophic ridge or crest of bone, associated with heavily striated and deeply pitted and depressed cortex: bone gives 'twisted' impression

Example image: Score 4

Figure 2.13: Femur gluteal score : FGSCO

The gluteal tuberosity is the main attachment for gluteus maximus, although other muscles attaching nearby, adductor magnus and vastus lateralis, may influence tuberosity shape. Gluteus maximus is a powerful hip extensor, and part of it, the iliotibial tract, acts as a stabiliser of the pelvis on the leg. The quadratus femoris attachment, the quadrate tubercule, situated anterior to the gluteal tuberosity, may run into this tuberosity in some individuals. Quadratus femoris is a lateral rotator of the hip joint. The focus in scoring this tuberosity remains on the posterior portion of the MSM, to avoid quadratus femoris influence and the spiral line.



1: Small patch of mildly roughened cortex, no hypertrophy or pitting

2: Small patch of roughened cortex, gentle line or crest with rounded profile, no pitting

3: Moderately rough or striated crest, restricted to proximal end

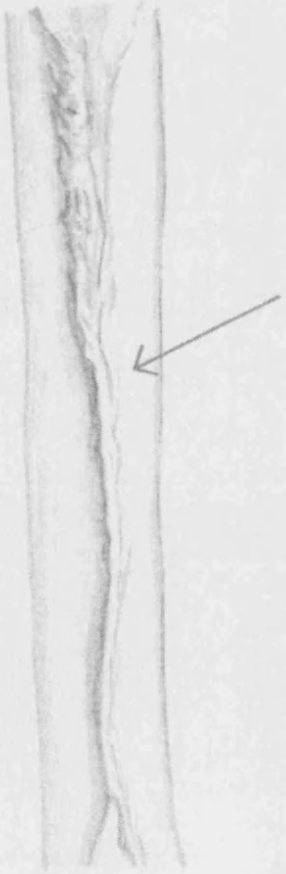
4: Moderate crest, extending along diaphysis, associated with pitting and rough, striated cortex

5: Extensive, strongly hypertrophic, angular and multiply striated crest

Example image: Score 3

Figure 2.14: Femur pilaster score : FPSCO

This score assesses the pilaster at the linea aspera on the posterior surface of the femur. The gluteal tuberosity may also run into the pilaster, but the focal point for this score is midshaft in order to avoid this influence. The pilaster may have distinct medial and lateral borders or crests, or may be a single structure. Attachments here are the adductor brevis, adductor magnus, adductor longus, short head of biceps femoris, vastus lateralis and vastus intemedius. This set of muscles adduct the hip joint, but some flex the knee as well.



1: Smooth, faint line, disappears in places along diaphysis

2: Distinct but broken line, single all along, little prominence from femoral surface

3: Distinct, unbroken, single crest, smooth profile, mild striations

4: Distinct crest, double edged in parts, hypertrophic and multiply striated: prominent from diaphysis

5: Strong and multiply striated crest, doubled for most of its length, with strong hypertrophic build-up around it: distinct from diaphyseal surface

Example image: Score 5

Cranial metric variables

The cranial metric variables used in this study are standard measurements collected following Howells (1973), and are listed below (Table 2.4). Error rates are calculated following White (White and Folkens, 2000).

Index formulae

The definition of robusticity as the size of a feature relative to an appropriate measure of body size works well for the long bones, where element length or epiphyseal dimensions can be used as the scaling variable. For craniofacial features, it is less straightforward to produce assessments of robusticity. In this study, features are scaled by cranial module, to produce indices as in the analysis of postcranial metric data. Cranial module is used because it is simple to calculate and is not a volumetric measurement (Beals et al., 1984), although it correlates well with cranial volume (Reinbold et al., 1985).

This set of variables are used to calculate indices of cranial and facial robusticity. The indices used and the formulae for calculating them are listed below (Table 2.5).

Table 2.4 : Cranial metric variables

Howells Code (1973)	Description	Error rate
GOL	Glabella occipital length	.836
BNL	Basion nasion length	1.216
BPL	Basion prosthion length	1.039
BBH	Basion-bregma height	.914
XFB	Maximum frontal breadth	.959
ZYB	Bi-zygomatic breadth	1.066
AUB	Bi-auricular breadth	1.068
JUB	Bi-jugal breadth	.878
ASB	Bi-asterionic breadth	1.024
XPB	Bi-parietal breadth	1.546
FOL	Foramen magnum length	1.377
FOB	Foramen magnum breadth	1.624
MDH	Mastoid height	2.437
MDB	Mastoid breadth	2.346
MAB	External palate breadth	.810
PLL	Palate length	1.262
PLD	Palate depth	1.336
IML	Inferior malar length	.856
XML	Maximum malar length	.760
NPH	Nasion-prosthion length	.879
NLH	Nasal length	.586
OBH	Orbit height	1.628
OBB	Orbit breadth	2.043
NLB	Nasal breadth	1.430
ZMB	Bimaxillary breadth	1.344
SSS	Subspinale subtense	1.788
FMB	Bifrontal breadth	1.862
NAS	Nasion subtense	3.169
EKB	Biorbital breadth	1.494
DKS	Subtense to dacryon	1.758
DKB	Dacryon-dacryon breadth	2.106
NDS	Subtense from DKB to nasion	2.488
WNB	Minimum nasal breadth	2.633
SIS	Simiotic subtense	2.613
SOS	Projection of supraorbital arch	1.688
GLS	Glabellar projection	3.646
FRC	Nasion-bregma chord	1.301
FRS	Frontal subtense	1.243
FRF	Frontal fraction	2.022
PAC	Bregma-lambda chord	.821
PAS	Parietal subtense	1.666
PAF	Parietal fraction	1.232
OCC	Lambda-opisthion chord	1.027
OCS	Occipital subtense	1.320
OCF	Occipital fraction	1.171

Table 2.5 : Cranial index formulae

Index	Formula
Cranial module	1/3 (GOL + XPB + BBH)
Facial height index	NPH / Cranial module
Malar height index	IML / Cranial module
Forehead breadth index	XFB / Cranial module
Zygomatic breadth index	ZYB / Cranial module
Gnathic Index	(BPL x 100) / BNL
Cranial Index	(XPB / GOL) x 100

Cranial scored variables

For surface features of the crania, a selection of the scored traits developed by Lahr (1994, 1996) were used. Lahr's work represents the first attempt to use strictly defined non-metric methods for assessing variation in cranial traits. These methods were developed from traits previously used for determining population history, rather than individual activity, so the emphasis in these scores is on the degree to which they reflect ethnic heritage, particularly in the East Asian and Australasian regions.

However, Lahr determined that although these traits show regional trends, they do not support the Multiregional Model of Modern Human Origins (1994). Furthermore, some of these traits (supraorbital torus, zygomatic trigone, infraglabellar notch, zygomax tuberosity, orbit rounding, and nasal saddle) might be influenced by cranial dimensions and robusticity and can be predicted from cranio-dental measurements (Lahr, 1994). Thus, they cannot be considered purely phylogenetic markers, and may reflect activity levels or biomechanical forces instead.

These craniofacial scores do not represent single muscle attachment sites, but are an assessment of the development of superstructures and general facial ruggedness. Chewing forces exerted by the temporal muscles on the mandible and facial skeleton may influence vault keeling, although the degree of expression of this depends on the width of the cranium. Dietary differences between populations may therefore be important here. Head and shoulder

activities may enhance the development of musculature in the nuchal area, and potentially influence occipital superstructures.

For the purposes of this study, the scores listed below (Table 2.6), will therefore be considered to be assessments of cranial rugosity. These cranial rugosity scores are included in this study in order to evaluate clearly their relationship to cranial size, shape and robusticity. They can also be used to compare cranial and postcranial rugosity, and the population-typical patterns of expression of both rugosity in modern humans.

Table 2.6: Cranial scored variables

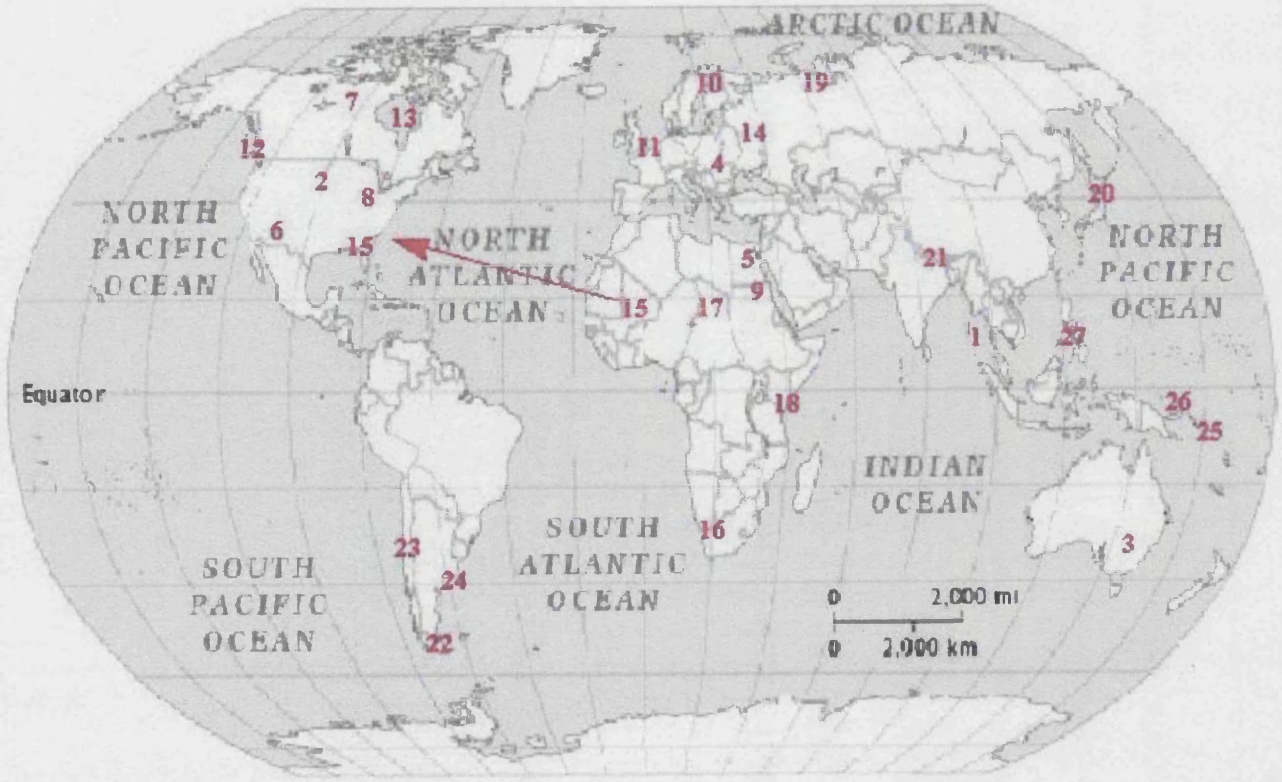
Code	**Lahr code (1994)**	**Variable description**	**Error rate (%)**
ST	AUS 1 (11)	Supraorbital torus	4.76
NS	EA 3 (3)	Nasal saddle profile	2.77
IN	AUS 4 (14)	Infraglabellar notch profile	2.76
ZT	AUS 11 (21)	Zygomaxillary tubercule	4.29
TR	AUS 15 (25)	Zygomatic trigone	3.72
SK	EA 1 (1)	Sagittal keeling	2.08
OA	EA 6 (6)	Orbital superior margin angle	5.09
OB	EA 6 (6)	Orbital superior lateral corner	6.15
OC	EA 6 (6)	Orbital inferior margin angle	4.14
RO	EA/AUS (30)	Orbital rounding	2.81
OT	AUS 19 (29)	Occipital torus	4.19
OCR	AUS 18 (28)	Occipital crest	3.64

Sample Description

The fifteen major populations represented in this sample form the main part of a large, diverse sample of modern humans widely distributed around the world (Figure 2.15) A range of subsistence methods and climatic regions are represented, so that the influence that lifestyle and climate have on robusticity and rugosity can be explored. Pertinent information on each population is listed below and summarised in terms of the sex (Table 2.7), climate and lifestyle parameters represented (Table 2.8).

A further fifty of the individuals in the database are not from these major populations. They are included to provide extra diversity in the database, particularly from regions where larger population samples are scarce. Individuals from these populations date from between 100 - 200 years ago, according to curatorial records.

Figure 2.15: World map showing major populations in data set



Adapted from National Geographic Society Xpeditions Online

Legend

Main populations	Code
1 Andamanese	AND
2 Arikara	ARI
3 Australian	AUS
4 Avar	AVA
5 Egyptian	EGY
6 Hawikuh	HAW
7 Inuit	INU
8 Jersey County, Ill.	JCI
9 Kerma	KER
10 Lapp	LAP
11 Poundbury	POU
12 Prince Rupert Harb.	PRH
13 Sadlermiut	SAD
14 Slavic	SLA
15 US Black	USB

Other Individuals

16 San
17 Chad
18 Kenya
19 Siberia
20 Japan
21 Nepal
22 Tierra del Fuego
23 Chile
24 Argentina
25 Solomon Islands
26 New Britain
27 Philippines

Table 2.7: Complete sample size

Population	Females	Males	Unknown	Total	Code
Andamanese	10	13	9	32	AND
Arikara	7	7	0	14	ARI
Australian	5	6	0	11	AUS
Avar	16	15	0	31	AVA
Egyptian	9	11	1	21	EGY
Hawikuh	11	10	0	21	HAW
Inuit	15	20	0	35	INU
Jersey County, Illinois	15	15	0	30	JCI
Kerma	6	7	1	14	KER
Lapp	3	3	0	6	LAP
Prince Rupert Harbour	9	11	0	20	PRH
Romano-British (Poundbury)	22	19	1	42	POU
Sadlermiut	9	7	0	16	SAD
Slavic	3	4	2	9	SLA
US Black	13	13	0	26	USB
Plus:					
African individuals (San, Pygmy, Chad)	7	5	2	14	SAF
Asian individuals (Siberia, Burma, Nepal, China, Japan)	1	7	1	9	ASI
S. American individuals (Tierra del Fuego, Chile, Patagonia, Argentina)	2	4	5	11	SAM
Australasian individuals (Solomons, New Britain)	2	3	0	5	SOL
Other individuals (Guam, Philippines, Grenada)	4	4	2	16	MIS
Total	169	195	24	388	

Population details

Andamanese (AND)

The remains of these indigenous inhabitants of the Andaman Islands, south of Myanmar, date between 100 and 150 years ago. Specimens are housed in the Natural History Museum, London and the Smithsonian Museum of Natural History, Washington D.C. The skeletal remains are from pre- and peri-contact people from across the archipelago, and are homogenous in their short, slight build (Stock and Pfeiffer, 2001). The Andaman people at this time used canoes for marine hunting and also ate wild pigs, yams and fruits (Radcliffe-Brown, 1922). They used stone tools and were habitually lightly clothed and unshod. Stock and Pfeiffer (2001) characterise this population as highly mobile at the coasts, with all individuals swimming regularly and using canoes, but having limited terrestrial mobility.

Arikara (ARI)

This collection consists of Plains Indians excavated from near the towns of Mobridge and Sully, South Dakota. The skeletal remains are housed in the Smithsonian Museum of Natural History, Washington D.C., but are likely to be repatriated in the near future. The remains date from the late coalescence period, thought to be between 200 and 300 years ago. This period saw the western migration and agglomeration of Plains Indian groups, provoked by the arrival of Europeans to the East Coast. There may be possible Wichita and

Mandan admixture with this population, but they date too early for European admixture to be likely (Owsley and Jantz, 1984).

The Arikara people at this time were a settled agricultural population living in villages along the central Missouri River Valley (Rogers, 1990). Buffalo, deer and antelope were hunted primarily by men, fish were trapped in river eddies, and birds hunted for their plumage. Family agricultural plots were worked predominantly by women. Corn, beans, squash and sunflowers were the main crops, supplemented by the collection of roots, nuts, and berries (Buikstra, 1988). Crop surpluses were traded to nomadic groups and neighbours (Tuross and Fogel, 1994).

Australian (AUS)

Individual specimens were collected in the late nineteenth and early twentieth centuries, and are housed in the Natural History Museum, London and the Smithsonian Museum of Natural History, Washington D.C. The individuals in this group come from all across the continent, and should therefore be considered a regional sample rather than a coherent and homogenous population. Subsistence for indigenous people across Australia at this time involved hunting of indigenous mammals, river fishing and gathering of wild plant foods, depending on local resources available (Collier, 1989).

Avar (AVA)

This collection is housed at the Vienna Natural History Museum, and comes from very late 20th century excavations at the Goldene Stiege cemetery site near Moedling, fifty miles from Vienna. The site is located south of the Danube river, and is dated to the 7th and 8th centuries.

The cemetery at Moedling is one of five in Austria associated with the Avar people, a group who have affinities further east in Hungary, and were known before this era to be semi-nomadic steppe warriors. By this period they were settled in the Carpathian basin, although horse riding remained an important activity, as is clear from art from the period (Bartosiewicz and Bartosiewicz, 2002). At this time, Avar subsistence consisted of a mixture of hunting and livestock farming, with some horticulture (Sobrensen and Thomas, 1989). The burials frequently include rich grave goods, including bronze weapons, and archaeologists report the Avars to have been a militarily successful population in their heyday, but who were ultimately crushed between the Christian Church in Western Europe and the Byzantine Empire.

Egyptian (EGY)

This material is held at the Vienna Natural History Museum, and was gathered over the course of excavations on the west side of Cheop's pyramid, and north of Chephren's pyramid from the 1940s to the 1970s at Giza. It dates

from the early pyramid building era, towards the end of the Old Kingdom, around 2,500 BC.

All individuals are from intentional burials, although the style and quality of the burials vary. Most are small pit tombs with sparse grave goods, some are simple sand graves with no walls. The demographics of the whole cemetery suggest that the people buried here were not from the poor working class, nor from the high status nobility. They are thought to be mostly priests, scribes and other middle class servants of the nobility involved in ceremonial and economic processes around the pyramids. In other words, this is not a representative sample of the Egyptian population as a whole, and may be considered to have been a protected, provisioned group of people (Murray, 2001).

Hawikuh (HAW)

This collection is housed in the Smithsonian Museum of Natural History, Washington D.C., and results from excavations in Northwest New Mexico. The remains come from mound burials in the catchment area of the Rio Grande, in the Pueblo 3 period. Their modern descendants are unknown. Southern desert dwellers in this period were cultivators of squash, corn and beans, supplemented by gathered wild foods (Dozier, 1970, Hayes et al., 1981).

Inuit (INU)

This collection is housed in the Canadian Museum of Civilization, Ottawa, and comprises individuals from the mainland Keewatin region of Nunavut. The ancestors of the Inuit peoples were the Thule, a population that arrived in the Nunavut area 1000 years ago, supplanting the existing Dorset, Pre-Dorset and Independence peoples (Taylor, 1963). Long before Martin Frobisher arrived in Baffin Bay in 1576, and officially 'discovered' the people for the benefit of Europeans, trade in iron and other artefacts had been going on between the Vikings in Greenland and this region.

Inuit subsistence at this time was predominantly hunting of marine mammals with harpoons, and land animals with bows, with some seasonal supplementation from wild plants (Irwin, 1984, Merbs, 1983). Dogs were used to hunt with and pull transport, and animal skins were prepared with teeth and scrapers. High impact activities such as coastal rowing, hunting and the dragging and preparation of carcasses produced high loads on the skeleton (Hawkey and Merbs, 1995).

Jersey County, Illinois (JCI)

This collection is housed in the Smithsonian Museum of Natural History, Washington D.C. The modern descendants of these people are unknown. The remains were excavated from a series of mounds in a 3-4 mile stretch of riverbank near Rosedale and Nutwood, Illinois. The remains are very well

preserved, and date to between 900-1100 AD. In this Woodland Period, Native American groups in this region are thought to have subsisted with a mixture of woodland hunting and river fishing, with gathered and cultivated plant foods (Keegan, 1987, Bridges, 1989, Bridges et al., 2000).

Kerma (KER)

These individuals come from a collection housed in the Duckworth Laboratory, Cambridge University. The collection is the result of excavations at Nubian sites in the Sudan, and the remains date from 2500-1500 BC (Reisner, 1982). Subsistence activity here consisted primarily of organised agriculture, based around cereals and livestock, although some classes of person would have been involved in artisanal, clerking or priestly roles instead (Kendall, 1997).

Lapp (LAP)

This small collection is housed in the Smithsonian Museum of Natural History, Washington D.C. The Lapps are Arctic Scandinavian people, still extant, who herd reindeer on a semi-nomadic basis. These remains are presumed to date from the late 19th and early 20th centuries, and were part of a collection exchange between the Smithsonian and a museum in Scandinavia. Admixture with neighbouring Scandinavian populations is possible.

Prince Rupert Harbour (PRH)

This collection is the result of a number of excavations in Northern British Columbia, near the Alaskan border. Excavated by Jerome Cybulski and colleagues, in collaboration with local First Nations, these remains are housed in the Canadian Museum of Civilisation, Ottawa. The collection dates between 3500 - 1500 years ago, a period in which the individuals lived in coastal villages. Subsistence primarily involved coastal resources, including gathered plant and animal foods, hunted mammals and fish. Fishing frequently required strenuous coastal rowing (Cybulski, 1990, 1992, 2001).

Romano-British (ROB)

This Roman Christian cemetery collection is housed in the Natural History Museum, London. Over 1000 graves from the east slope of Poundbury Hill, west edge of Dorchester, Dorset were excavated in the 1970s and 1980s. The site is near an Iron Age hill fort reported by Suetonius to have been taken by the Roman general Vespasian in his campaign AD 44-45. The people evicted from this fort settled at the base of the hill, and prospered as livestock and arable farmers (Green, 1987). Graves here are varied, mostly Christian (77%), in mausoleums, lead lined coffins and stone, decorated with murals, as well as wood. The population is physically homogenous, suggesting little immigration, and that Roman Britons here really were British, rather than settled Romans (Farrell and Molleson, 1993).

Sadlermiut (SAD)

These people lived on Southampton Island and the nearby Coates Island in Hudson Bay. They were uncontacted by Europeans (except perhaps the Norse) until 1824, as compared to the surrounding mainland groups who had contact with Europeans since 1576 (Merbs, 1983). They became extinct in the winter of 1902-3, when they were exposed to a virulent gastric disease carried by European passengers on a visiting boat. While the surrounding Inuit populations from mainland Nunavut appear to be descended from the Thule people, the Sadlermiut show signs of descent from the Dorset people as well, particularly in elements of their material culture.

Southampton Island is separated from the mainland by a rough and turbulent sea passage, and on this basis, as well as on their late European contact and material cultural differences, Merbs describes them as a genetic isolate. However, they do share subsistence techniques with their neighbours, hunting with harpoon and bow, coastal boating, using dogs to hunt with and pull transport, and preparing skins with teeth and scrapers (Irwin, 1984)

Sites included in the Sadlermiut group include Native Point (bay on south coast of island), and Silumuit, a site from the west coast of Southampton Island. Much of the material in the CMC Sadlermiut collection was excavated by Laughlin and Merbs during a series of digs between 1956 and 1970 (Merbs, 1983, plus archived field notes at the Canadian Museum of Civilisation)

Slavic (SLA)

This collection is housed at the Vienna Natural History Museum. It comes from excavations in 1987 and 1990 at a cemetery site near Gars-Thunau, not far from Vienna. This site is located north of the Danube river, and the collection is dated at around 900 BC.

The individuals at this site were interred directly in earth, along with varied grave goods. The ethnic affinity of the people in this burial is thought, from the cultural artefacts, to be Slavic. This cemetery has links to others east of Austria, and dates from a time when archaeologists suggest there was a westward migration of Slavic people (Curta, 2001).

US Black (USB)

These individuals are from the Terry Collection at the Smithsonian Natural History Museum, Washington D.C., a hospital collection compiled in the 20th century (Hunt, 2001). Occupation, cause of death and age at death are known in many cases, and associated materials for some individuals include death masks, height and weight and photographs. The complete collection includes black and white US individuals, but only black individuals are included here. Socioeconomically speaking, the people in this collection are unlikely to have been wealthy or of high status (Angel et al., 1987). Many are listed as having held domestic, clerical or labouring jobs.

Figure 2.8 : Summary of Population Characteristics

Population	Climate	Lifestyle Code	Subsistence	Code
Andamanese	Hot	H/F	Coastal fishing, hunting and gathering	AND
Arikara	Temperate	C/H	Plains hunters, settled agriculturalists	ARI
Australian	Hot	H/G	Hunters, fishers and gatherers	AUS
Avar	Temperate	H/H	Semi-nomadic hunters and herders	AVA
Egyptian	Hot	A	Stratified agricultural society	EGY
Hawikuh	Hot	C/H	Agricultural society, with hunting	HAW
Inuit	Cold	H/F	Hunters, coastal fishing	INU
Jersey County, Illinois	Temperate	C/H	Woodland hunting, river fishing, gathered and cultivated plant foods	JCI
Kerma	Hot	A	Stratified agricultural society	KER
Lapp	Arctic	H/H	Hunters and herders	LAP
Prince Rupert Harbour	Temperate	H/F	Coastal fishing, hunting and gathering	PRI
Romano-British	Temperate	A	Stratified agricultural society	ROB
Sadlermiut	Arctic	H/F	Hunters, coast fishing	SAD
Slavic	Temperate	H/H	Semi-nomadic hunters and herders	SLA
US Black	Temperate	A	Stratified industrial society	USB

H/F = hunt/fish, H/G = hunt/gather, H/H = hunt/herd, C/H = cultivate/hunt, A = agriculture

Sample categorisation

The details for the major populations are summarised above with their categorisations for the purposes of this study (Table 2.8). The distribution of the categories for the whole data set are summarised below (Table 2.9). Individuals are categorised as being male, female or of unknown sex, on the basis of pelvic examination, and curatorial expertise. The age range is divided into three categories, the young adults, aged up to 30 years, those aged between 30 and 50 years, and the older adults, over 50. Individuals of unknown age or sex are excluded from analyses of these variables.

The climatic range is also reduced to three categories, cold, temperate and hot. Cold includes Arctic and near-Arctic populations, and temperate includes populations with seasonal temperature variations, where warm summers and cool or cold winters are typical. The hot category includes those in tropical, sub-tropical or desert conditions, where no cool phase to the year is present, although precipitation rates may vary.

Lifestyles are harder to categorise, and five groups are necessary. For this study, the important components of subsistence strategy are levels of mobility, such as daily journey distances or regular transhumance, and the physical activities performed in order to obtain food and other resources. The hunt/gather category includes populations where foraging and hunting journeys are significant and regular parts of life, and where technological assistances to hunting and foraging efficiency are minimal. The hunt/fish

category includes those marine-mobile populations where coastal foraging, hunting of marine mammals or sea fishing comprise the bulk of subsistence activity.

The hunt/herd category includes those populations where animal domesticates are the primary source for food (and other resources), but where hunted and foraged food supplements this at some periods of the year. These populations may be semi-settled, practising transhumance between regular seasonal sites for grazing or shelter. The cultivate/hunt group includes settled populations that practice cultivation on a small scale, typically with family or village plots and no mechanisation of horticultural activities. Again, hunting and foraging may regularly supplement resources. The agricultural category includes those populations where agriculture is large in scale, highly organised, and does not involve all members of a population. Surpluses are regularly produced and stored, society is stratified and individuals perform diverse labour activities.

The populations are also categorised by continent, a classification included to act as a proxy for ethnic heritage. In a comparison between populations on two continents, where age, sex, climate and lifestyle are equivalent, then the remaining difference can be attributed to ethnic heritage, which is the closest these data can get to genetic differences.

Table 2.9: Distribution of individuals among climate, lifestyle and continent categories

	Hot				Temperate				Cold			Total
	H/F	H/G	C/H	A	H/F	H/H	C/H	A	H/F	H/G	H/H	
Africa		17	14	47								78
Europe						40		41			6	87
Americas			21		20		44		56	5		146
Asia	33		1				4	5			1	44
Australasia	7	12										19
Total	40	29	36	47	20	40	48	46	56	5	7	374

H/F = hunt/fish, H/G = hunt/gather, H/H = hunt/herd, C/H = cultivate/hunt, A = agriculture

Individuals are not distributed evenly among the climate, lifestyle and continent categories (Table 2.9). This is in part because some subsistence strategies are not viable under certain climatic conditions, and in part because some continents contain only some of the global climatic range. For example, agriculture is not viable in Arctic conditions, and Africa and Australasia contain only hot climatic regions (at least for the purposes of this sample).

However, in the statistical tests used in this study, uneven sample sizes are not a major problem. In Discriminant Function Analysis, removal of small samples satisfies the demand that the number in the smallest sample should be greater than the number of dependent variables. The only limitation with multi-way ANOVA is that the relative importance of different influences on the dependent variables is harder to discern. Results must therefore be interpreted conservatively, within the limitations of this experimental design.

Individuals are also spread unevenly among the age and sex categories. For example, the age categories are of significantly different sizes (Chi-square sig. .000), since there are fewer older adults than young and middle-aged adults (Table 2.10). However, there are equivalent numbers of males and females (Chi-square sig. .364), and equivalent numbers within populations, as far as possible.

Table 2.10: Distribution of individuals among age and sex categories

	Hot			Temperate			Cold			Total		
	Female	Male	Unknown	Female	Male	Unknown	Female	Male	Unknown	Female	Male	Unknown
Under 30	29	38	5	35	31	1	11	13		75	82	6
30 - 50	25	23	7	29	36	1	10	14	2	64	73	10
Over 50	9	7		9	10		5	6	1	23	23	1
Unknown	3	4	2			2	1	2	3	4	6	7
Total	66	72	14	73	77	4	27	35	6	166	184	24

Chapter 3 : Postcranial Metric Results

Postcranial metric variation in modern humans is explored here using classic indices. Descriptive statistics and population profiles are produced for each set of variables by category. The variables examined are indices of diaphyseal robusticity, diaphyseal circularity, epiphyseal robusticity and body proportions. All index formulae, and criteria for categorisation in terms of age, sex, climate, lifestyle or continent, are described in Chapter 2. The component variables used to calculate these indices, bone lengths and epiphyseal and diaphyseal dimensions, are investigated first. This means that it is possible to trace variation in the indices to the variation in the components of the index, for example, to show whether variation in a diaphyseal robusticity index derives from variation in bone length or diaphysis diameter, or both.

Bone Length

As a major component of stature, bone length is an important variable in assessing relative size diversity in modern humans. Bone length variability needs to be well characterised before exploring index diversity.

One-way ANOVA

Only clavicle length shows significantly more variation between age groups than within age groups, a result supported by post-hoc tests (Tamhane sig. p= .002)

(Table 3.1). All bone lengths differ significantly between males than females, with males being larger than females (Table 3.2). Post hoc tests support this (Tukey and Tamhane sig. p= .000) in all cases.

Table 3.1: One-way ANOVAs for bone lengths

	Age		**Sex**		**Climate**		**Lifestyle**		**Continent**	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Tibia functional length	1.059	.367	20.601	.000*	11.014	.000*	16.123	.000*	19.779	.000*
Ulna functional length	1.768	.153	43.230	.000*	24.353	.000*	17.529	.000*	8.507	.000*
Clavicle maximum length	4.688	.003*	26.861	.000*	13.430	.000*	18.539	.000*	36.060	.000*
Radius functional length	.719	.541	47.181	.000*	33.239	.000*	19.260	.000*	9.352	.000*
Humerus functional length	1.838	.140	29.742	.000*	9.914	.000*	16.611	.000*	19.446	.000*
Femur functional length	1.186	.315	39.858	.000*	2.216	.111	11.591	.000*	17.125	.000*

* = p <.005

Table 3.2 : Descriptive statistics for long bone lengths, by age and sex

Sex	Age	Ulna functional length			Clavicle maximum length			Radius functional length			Humerus functional length			Tibia functional length			Femur functional length		
		Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
Female	Under 30	326.59	25.02	72	211.02	14.17	72	132.26	13.32	75	208.45	15.62	74	288.81	22.02	74	408.21	26.92	73
	30 - 50	331.40	20.25	59	215.56	15.66	61	137.58	10.55	64	213.11	15.45	60	292.89	17.78	61	409.43	22.56	62
	Over 50	324.81	18.91	20	211.28	16.73	22	135.82	9.80	23	208.02	16.52	19	290.34	17.97	22	405.50	16.20	23
Male	Under 30	342.59	30.15	82	228.33	20.08	81	142.65	14.81	82	227.76	19.28	78	304.07	24.26	82	429.98	33.84	82
	30 - 50	349.59	29.72	68	232.51	18.72	71	146.34	11.48	73	230.71	19.28	69	310.67	20.25	72	436.89	28.85	73
	Over 50	350.05	19.88	23	231.87	16.33	22	152.13	11.65	23	228.47	18.53	23	312.68	14.89	23	444.34	18.46	23

Table 3.3: Descriptive statistics for long bone lengths, by climate and lifestyle

Climate	Lifestyle	Ulna functional length			Clavicle maximum length			Radius functional length			Humerus functional length			Tibia functional length			Femur functional length		
		Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
Hot	hunt/fish	314.88	23.27	29	209.33	15.50	30	116.36	12.30	30	209.51	16.78	28	272.35	20.49	29	387.04	26.44	30
	hunt/gather	339.44	33.52	21	220.69	20.24	21	133.38	14.94	21	219.51	20.64	20	293.19	25.84	21	419.95	35.39	21
	cultivate/hunt	346.27	26.99	33	227.10	17.43	34	142.19	8.61	34	226.75	17.30	32	301.63	20.38	34	424.51	28.61	34
	agriculture	359.96	24.61	42	235.16	16.71	45	149.68	10.47	46	232.25	18.17	44	313.88	20.64	45	442.37	29.71	46
	Total	342.44	31.29	125	224.75	19.69	130	137.49	17.00	131	223.64	19.89	124	297.95	26.36	129	421.47	35.96	131
Temp.	hunt/fish	318.74	26.36	16	222.05	16.62	20	146.04	8.52	20	218.79	15.18	18	295.67	17.35	20	406.92	23.24	20
	hunt/herd	348.45	23.09	37	231.19	18.82	37	142.64	10.56	38	227.09	19.35	36	310.18	19.99	37	432.39	27.50	36
	cultivate/hunt	349.56	20.05	45	233.30	13.75	44	147.26	11.30	48	231.57	14.04	44	309.09	15.60	45	431.57	21.96	47
	agriculture	331.54	22.35	43	217.96	16.61	41	142.01	9.95	44	219.10	17.25	43	301.05	20.73	44	422.15	27.10	44
	Total	340.28	24.69	141	226.74	17.54	142	144.39	10.55	150	224.99	17.37	141	305.11	19.20	146	425.60	26.35	147
Cold	hunt/fish	326.76	15.61	49	205.01	13.15	48	137.64	9.89	50	200.54	13.52	49	292.45	17.61	50	421.46	21.99	49
	hunt/gather	324.83	10.31	3	217.67	17.64	3	138.67	8.50	3	216.67	17.67	3	287.17	20.19	3	401.08	21.32	3
	hunt/herd	284.92	11.90	6	197.79	9.41	6	126.66	10.09	6	195.17	7.18	6	275.67	13.10	6	375.08	20.23	6
	Total	322.33	19.64	58	204.92	13.36	57	136.57	10.26	59	200.82	13.64	58	290.47	17.81	59	415.61	25.93	58

All bone lengths except femur vary significantly with climate, although post-hoc test results indicate significance only between certain climatic categories (Tables 3.3 and 3.5). Both the humerus and clavicle are significantly shorter in hot climates than temperate climates. The ulna, radius and tibia are significantly longer in hot climates than cold climates, whereas the reverse is the case for the clavicle. The ulna, humerus, tibia and radius are significantly longer in temperate climates than cold climates.

These findings support the established association between cold climates and reduced distal limb length as a heat retaining adaptation. The association between short clavicle length and hot climates may be connected to factors linking narrow torsos with high temperatures (The Cylinder Model, Ruff, 1994). However, no explanations have previously been offered to explain the significantly shorter humerus length in hot climates. The greatest differences are found between cold climates and other categories, rather than between hot climates and other categories. This suggests that it is the extreme cold, rather than the absence of warmth, that is the trigger for reduction in limb length.

Table 3.5: Summary of significant post-hoc results for bone length by climate

Climate	Temperate	Cold	
Hot	Humerus ** Clavicle **	Ulna ** Tibia **	Clavicle ** Radius**
Temperate		Ulna ** Tibia **	Humerus ** Radius **

Tukey test ** = p<.005, * = p<.05

Table 3.4: Descriptive statistics for long bone lengths, by population and continent

Continent	Popn.	Tibia functional length			Clavicle maximum length			Radius functional length			Humerus functional length			Ulna functional length			Femur functional length		
		Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
Africa	TER	364.04	24.10	27	236.37	17.35	27	150.21	12.77	27	234.68	17.26	27	317.10	19.12	27	449.33	28.06	27
	SAF	324.25	33.55	9	206.25	18.45	9	130.92	15.90	9	204.06	20.11	8	274.58	24.86	9	401.14	38.24	9
	EGY	353.63	24.12	16	232.86	15.71	19	148.12	6.92	20	228.31	18.84	18	308.55	21.88	19	433.09	29.22	20
	KER	365.17	24.78	13	236.54	20.15	13	142.38	9.12	13	237.88	18.73	12	309.69	24.26	13	446.79	26.78	13
Subtotal		356.19	28.56	65	231.44	19.93	68	145.61	12.69	69	229.74	20.63	65	307.67	25.17	68	437.86	33.03	69
Europe	AVA	349.32	24.30	30	231.17	19.89	30	142.89	10.60	31	227.19	20.63	29	311.20	21.39	30	433.33	28.36	30
	LAP	284.92	11.90	6	197.79	9.41	6	126.66	10.09	6	195.17	7.18	6	275.67	13.10	6	375.08	20.23	6
	POU	333.16	21.94	38	218.29	16.26	36	141.98	9.29	39	219.98	16.91	38	302.61	20.38	39	423.08	26.68	39
	SLA	344.71	17.99	7	231.24	14.59	7	141.57	11.13	7	226.71	14.10	7	305.79	12.55	7	427.67	24.45	6
Subtotal		336.57	27.24	81	222.77	19.46	79	141.18	10.64	83	221.32	19.26	80	304.05	21.46	82	423.66	30.10	81
Americas	ARI	351.56	17.15	14	230.12	15.63	14	150.07	9.55	14	231.23	13.76	14	306.92	17.47	13	427.69	24.12	14
	HAW	333.99	20.88	20	221.08	13.12	20	142.72	8.18	20	220.08	12.67	20	296.49	16.64	20	409.95	20.14	20
	JCI	347.59	19.94	27	234.37	11.51	26	147.37	11.91	30	231.37	14.01	26	310.92	14.04	28	433.27	19.00	29
	INU	329.30	14.49	33	205.84	13.25	32	138.27	9.94	34	201.41	13.45	33	291.10	18.61	34	419.18	22.88	33
	PRH	318.74	26.36	16	222.05	16.62	20	146.04	8.52	20	218.79	15.18	18	295.67	17.35	20	406.92	23.24	20
	SAD	321.52	16.98	16	203.36	13.23	16	136.30	9.98	16	198.75	13.90	16	295.31	15.43	16	426.17	19.87	16
	SAM	324.83	10.31	3	217.67	17.64	3	138.67	8.50	3	216.67	17.67	3	287.17	20.19	3	401.08	21.32	3
Subtotal		333.89	21.76	129	218.87	17.82	131	143.03	10.79	137	215.92	18.74	130	298.68	18.12	134	420.33	23.23	135
Asia	AND	307.60	11.93	23	205.38	10.12	24	111.88	7.87	24	205.05	9.84	23	265.23	12.18	23	379.50	16.59	24
	ASI	337.54	34.39	7	224.56	22.86	8	134.00	9.77	8	223.79	24.55	6	293.22	21.48	8	414.94	35.89	8
	JAP	317.66	27.49	4	212.75	23.07	4	141.75	18.01	4	210.19	22.80	4	289.19	24.96	4	417.94	36.76	4
Subtotal		314.95	22.92	34	210.46	16.77	36	120.11	15.22	36	209.08	16.18	33	274.36	20.30	35	391.65	29.30	36
Australasia	AUS	349.23	30.81	11	232.20	14.58	11	135.43	15.30	11	230.07	14.38	11	307.84	17.01	11	433.09	27.67	11
	POL	360.75	24.16	4	239.06	10.27	4	138.44	5.87	4	241.25	11.29	4	313.25	7.73	4	436.06	26.64	4
Subtotal		352.30	28.82	15	234.03	13.58	15	136.23	13.29	15	233.05	14.19	15	309.28	15.02	15	433.88	26.47	15

All long bone lengths vary significantly by lifestyle (Tables 3.1 and 3.3), although post hoc tests reveal significance only between certain subsistence strategies (Table 3.6). The clavicle of agricultural people is significantly longer than that of hunter/gatherers, but the rest of the significant results refer to comparisons between the hunter/fisher people and other lifestyles. In all cases, bones are significantly shorter in hunter/fisher people than in other relevant groups.

Table 3.6: Summary of significant post-hoc results for long bone length by lifestyle

	Hunt/gather	**Hunt/fish**	**Hunt/herd**	**Cultivate/hunt**	**Agriculture**
Hunt/gather		Ulna **			Clavicle *
		Femur *			
		Tibia **			
		Radius **			
Hunt/fish			Ulna **	Ulna **	Humerus **
			Humerus **	Humerus **	Femur **
			Femur **	Femur **	Tibia **
			Tibia **	Tibia **	Radius **
			Radius **	Radius **	Clavicle **
			Clavicle **	Clavicle **	

** = p<.005, * = p<.05 Tukey test: Clavicle, Ulna, Radius, Tibia, Femur; Tamhane test: Humerus,

All bone lengths vary significantly by continent with a one-way analysis (Tables 3.1 and 3.4), and the post-hoc test results reveal a complex pattern of significance between particular pairs of continents (Table 3.7). The Asian continent is significantly different in all bone lengths to all other continents, being generally smaller individuals. The Australasian clavicle is significantly different to those of African or American populations, being shorter on average. The European and African populations differ

only in the leg bone lengths, in that the African populations are on average longer in the leg. The African and American groups are significantly different for all limb bones, in that the American average is shorter.

Table 3.7: Summary of significant (.05) post-hoc tests for bone length by continent

	Europe	Americas	Asia	Australasia
Africa	Tibia ** Femur *	Humerus * Ulna ** Radius ** Femur ** Tibia **	Clavicle ** Ulna ** Humerus ** Tibia ** Radius ** Femur **	Clavicle *
Europe			Clavicle ** Tibia ** Humerus ** Femur ** Ulna * Radius *	
Americas			Clavicle ** Tibia ** Humerus ** Femur **	Clavicle *
Asia				Clavicle ** Tibia ** Humerus ** Femur ** Ulna * Radius *

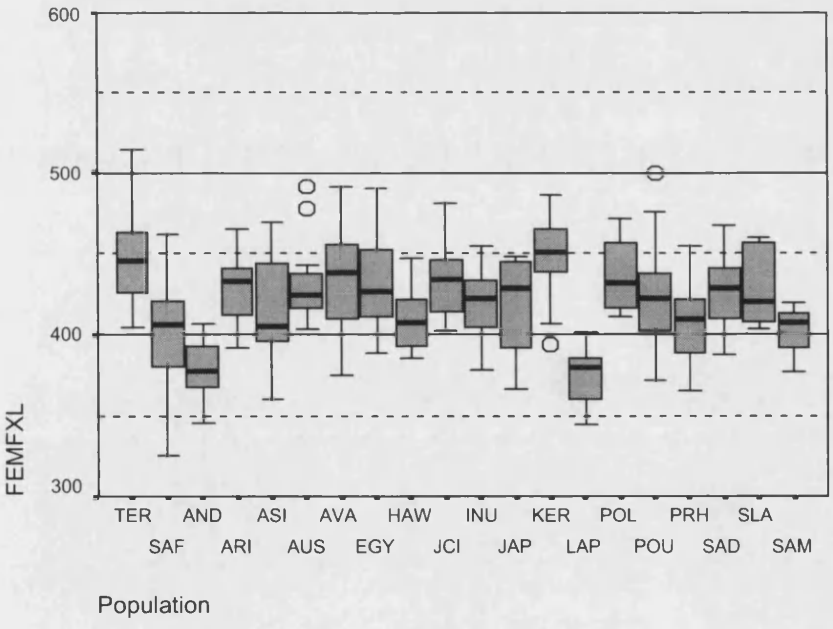
** = p<.005, * = p<.05 Tukey test: Humerus , Clavicle, Tibia, Femur Tamhane test: Ulna, Radius

Population profiles

Plotting the mean bone lengths for the major populations in the sample demonstrates how the influences explored above translate into (or derive from) typical profiles for each population. These plots show very similar patterns for all bones, so only one box plot, for femur functional length, is shown (Figure 3.1). Differences in the relative lengths of long bones are better explored through the analyses of body shape indices that follow.

The Terry, Avar and Kerma populations have mean femoral lengths over 440 mm (and have long bones generally). The 75th percentile for the whole data set is 442.7 mm. The Arikara, Australian, Avar, Egyptian, Jersey County Illinois, Poundbury, Sadlermiut and Slavic populations have mean femoral lengths between 420 and 440 mm, and could be categorised as having medium-high bone lengths. The Small African, Asian, Hawikuh, Inuit, Prince Rupert Harbour and South American groups have low-medium bone lengths, with femoral means between 400 and 420 mm, compared with the 25th percentile, which is 402.8 mm. The Lapp and Andaman populations have notably short femora, with a mean under 400 mm, and also short bones throughout the skeleton.

Figure 3.1: Boxplot of femur functional length, by population



Five-way ANOVA

The tibia and radius lengths are affected significantly by sex or climate, if the other categories remain constant (Table 3.8). The femur and clavicle lengths are affected significantly only by sex, and the humerus length is affected significantly by sex and lifestyle category. Ulna length is affected significantly by all categories except age.

The long bones differ considerably in the degree to which their length variation is associated with variance in the five categories explored here. Sex is a significant influence for all bones, such that if all else is equal, a significant difference in means between the sexes remains. Age is not a significant influence on long bone length, once adult age is attained, and continent appears to be of marginal influence, showing a significant effect only on the ulna length.

Climate affects the three distal limb elements (tibia, radius and ulna) significantly, providing strong support for the shortening of distal limbs in cold climates. Lifestyle affects two of the arm bones, the ulna and humerus, significantly, suggesting that where all else is held constant, different lifestyles affect these bones in different ways. That the upper body is more affected than the lower body is not surprising, since upper body activities are more variable than the predominantly locomotor activities of the lower limbs. Body size differences between the populations may be responsible for the significant results in the five-way ANOVA results.

Table 3.8: Summary of five-way ANOVA results, bone lengths

	TIBFXL				RADFXL			
category excluded	SS	df	F	sig.	SS	df	F	sig.
none	93467.26	252			36361.07	251		
age	104327.2	292	0.963287	ns	41666.64	291	0.9884	ns
sex	139443.7	286	1.31454	**0.05**	71926.57	285	1.742134	**0.01**
climate	122343	266	1.240048	**0.05**	50924.44	266	1.321544	**0.05**
lifestyle	124781.5	276	1.218939	ns	48130.71	275	1.208166	ns
continent	117740.5	268	1.184492	ns	46667.31	266	1.211067	ns

	ULNFXL				HUMFXL			
category excluded	SS	df	F	sig.	SS	df	F	sig.
none	34396.42	255			62509.99	260		
age	41125.42	296	1.03002	ns	71200.71	301	0.983879	ns
sex	69651.17	289	1.786724	**0.01**	102639.4	294	1.45208	**0.01**
climate	50679.53	271	1.386405	**0.05**	74028.76	276	1.115617	ns
lifestyle	48833.67	281	1.288368	**0.05**	87508.81	286	1.272652	**0.05**
continent	45330.38	272	1.235513	**0.05**	81280.91	277	1.220486	ns

	CLMXL				FEMFXL			
category excluded	SS	df	F	sig.	SS	df	F	sig.
none	19137.89	266			117298.6	262		
age	21712.84	307	0.983028	ns	135756.2	303	1.00075	ns
sex	31852.66	300	1.475748	**0.01**	189953	296	1.433385	**0.05**
climate	24065.83	282	1.186149	ns	145546.3	278	1.169405	ns
lifestyle	22786.32	292	1.084623	ns	151508.1	288	1.175038	ns
continent	22667.43	283	1.113277	ns	144100.9	279	1.153642	ns

There are significant interactions between these five categories, both with the full five-way ANOVA, and when single categories are excluded in the four-way ANOVAs (Table 3.9). When two or more categories exhibit significant interaction, they vary non-randomly with respect to one another. Sex most commonly has significant interactions with other categories, particularly climate, continent and lifestyle. These interactions remain significant with all permutations of categories included or excluded, and are thus considered stable. The degree of sexual dimorphism in bone

Table 3.9: Summary of significant interactions between categories for long bone length

Significant interactions between two categories from four- and five-way ANOVA

Category excluded	age x sex	age x lifestyle	age x climate	age x continent	sex x lifestyle	sex x climate	sex x continent	lifestyle x climate	lifestyle x continent	climate x continent
None		Ulna *	Ulna * Clavicle*		Ulna * Humerus **	Ulna ** Clavicle ** Radius *	Tibia ** Ulna ** Radius ** Humerus ** Femur *			
age					Ulna ** Radius * Humerus **	Ulna ** Radius **	Tibia ** Ulna ** Clavicle * Radius * Humerus **			
sex										
lifestyle	Clavicle *					Ulna ** Clavicle ** Radius **	Tibia ** Ulna ** Clavicle ** Radius ** Humerus **			Tibia ** Clavicle ** Femur **
climate					Ulna * Radius ** Humerus ** Femur *		Tibia * Humerus **			
continent			Ulna ** Radius ** Femur *		Tibia *	Ulna ** Radius **		Tibia ** Ulna ** Clavicle ** Radius ** Humerus ** Femur **		

Significant interactions between three categories from four- and five-way ANOVA

Category excluded	sex x lifestyle x continent	age x lifestyle x climate	sex x lifestyle x climate
climate	Tibia ** Ulna * Radius * Humerus ** Femur *		
continent		Clavicle* Radius *	Ulna * Clavicle * Humerus **

* = p < .05, ** = p < .01

length can therefore be considered to vary between lifestyle, climate and continental groups.

There are few significant interactions between age and other categories, showing that age has little effect on how bone length is affected by other categories such as climate and lifestyle (Table 3.9). The exceptions are those between age and lifestyle (ulna) and age and climate (ulna and clavicle). Age-related change in bone length is therefore mediated by climatic zone for the clavicle, and by both climatic zone and subsistence strategy for the ulna.

The clavicle continues to grow into adulthood, being the last to ossify completely, as late as age 30 (White and Folkens, 2000). Strenuous upper body activity before this age may promote or stunt clavicle growth through unknown mechanisms, and the activity patterns may be mediated by climate. Alternatively temperature alone may affect clavicle length through selection for torso breadth as a thermoregulatory adaptation.

Climate and lifestyle also show several significant interactions, particularly with age, continent and one another, but these interactions only become significant once other categories are removed. If the category sex is removed, no interactions between the remaining categories are significant. Since sex is the primary source of variation in bone length, this means that the interactions between climate, lifestyle and continent are only significant when the variation that is otherwise attributed to sexual dimorphism is re-allocated to these remaining categories. So, while these

interactions are interesting, they cannot be considered to be as important as the interactions that remain significant when no categories are removed. For this reason, only the interactions that are significant with no categories removed will be presented and discussed in later sections.

Diaphyseal diameters

Diaphyseal diameters are components of both the robusticity and circularity indices. As such, variation in these variables needs to be explored before the index results can be interpreted accurately. Descriptive statistics for the diaphyseal diameters of the long bones in this study are presented below (Tables 3.11 - 3.15). These include both the anterior-posterior and medio-lateral diameters at all the positions along the diaphyses that are used in the construction of indices. While the robusticity indices use only mean diameters, the circularity indices use both diameters at each position.

One-way ANOVA

Table 3.10: One-way ANOVAs for diaphyseal diameters

	Age		**Sex**		**Climate**		**Lifestyle**		**Continent**	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
TMSAP	4.376	.005*	25.942	.000*	10.820	.000*	4.463	.002*	27.753	.000*
TMSML	.571	.634	43.351	.000*	5.637	.004*	9.086	.000*	6.125	.000*
UMSAP	11.734	.000*	61.987	.000*	11.056	.000*	1.259	.286	8.579	.000*
UMSML	3.235	.022*	40.216	.000*	26.868	.000*	9.708	.000*	7.371	.000*
USBAP	2.922	.034*	38.172	.000*	40.314	.000*	.556	.695	18.036	.000*
USBML	2.321	.075	71.879	.000*	11.332	.000*	5.729	.000*	3.769	.005*
CMSMX	1.330	.264	50.682	.000*	8.544	.000*	18.503	.000*	16.389	.000*
CMSMN	3.979	.008*	55.651	.000*	4.533	.011*	7.902	.000*	8.134	.000*
RMSAP	3.486	.016*	81.556	.000*	6.827	.001*	5.498	.000*	9.120	.000*
RMSML	3.816	.010*	38.836	.000*	25.203	.000*	11.425	.000*	12.660	.000*
HMSAP	4.989	.002*	37.704	.000*	32.462	.000*	6.282	.000*	14.433	.000*
HMSML	3.138	.026*	44.863	.000*	25.987	.000*	2.801	.026*	17.383	.000*
FMSAP	1.951	.121	67.890	.000*	14.432	.000*	1.881	.113	12.609	.000*
FMSML	6.972	.000*	37.919	.000*	41.211	.000*	10.622	.000*	31.329	.000*
FSTAP	2.385	.069	36.444	.000*	29.393	.000*	9.084	.000*	19.533	.000*
FSTML	7.553	.000*	29.254	.000*	77.900	.000*	10.206	.000*	45.479	.000*

* = p< 0.05

One-way ANOVA reveals significantly more between-group than within-group variance for all diaphyseal diameters by sex (Table 3.10). This is supported completely by post hoc tests between males and females (All significant to .000). Males have larger diaphyseal diameters than females at all points measured on the skeleton. By age, the pattern is slightly more complex. Tibia midshaft medio-lateral diameter (TMSML), ulna sub-brachial medio-lateral diameter (USBML) and clavicle midshaft maximum diameter (CMSMX) show no significant difference between within-group and between-group variance (Table 3.10). This finding is supported by post hoc tests between the age classes. The post hoc tests also reveal that for the remaining variables, there is only significant difference between certain, and not all age classes (Table 3.13).

There are no significant differences in diaphyseal diameters between the 30-50 age class and the over 50 age class. The diameters that show significant change with age are all significantly different between the youngest and middle age classes, and only four variables show significant difference between the youngest and oldest age classes. These are ulna midshaft anterior-posterior diameter (UMSAP), clavicle midshaft minimum diameter (CMSMN), femur midshaft medio-lateral diameter (FMSML) and femur sub-trochanter medio-lateral diameter (FSTML). These variables show significant increase with age throughout life. The remaining variables show increase with age up to the 30-50 age category, but then no further significant change.

Table 3.11: Descriptive statistics for diaphyseal diameters, by age

Age Category	TMSAP			TMSML			HMSAP			HMSML			FMSAP			FMSML			FSTAP			FSTML		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Under 30	25.72	3.54	154	21.85	2.78	154	19.77	2.63	156	19.13	2.79	156	26.67	3.29	155	24.89	3.05	155	23.78	3.20	155	29.77	3.67	155
30 - 50	26.88	3.06	127	22.20	2.59	127	20.81	2.55	132	20.09	2.84	132	27.49	2.93	135	26.03	2.63	135	24.53	2.86	135	31.36	3.44	135
Over 50	26.69	3.07	43	22.23	2.52	43	20.76	2.65	45	19.85	2.82	45	27.42	3.12	46	26.32	2.28	46	24.79	2.94	46	31.80	3.38	46

	UMSAP			UMSML			USBAP			USBML			RMSAP			RMSML			CMSMX			CMSMN		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Under 30	11.72	1.64	153	14.41	2.21	153	17.58	2.80	153	14.92	2.05	153	10.98	1.44	152	14.29	2.03	152	11.63	1.87	157	8.83	1.30	157
30 - 50	12.23	1.65	132	15.06	1.90	132	18.41	2.67	132	15.50	2.15	132	11.40	1.33	129	14.96	1.82	129	11.96	1.92	137	9.24	1.37	137
Over 50	12.36	1.31	44	14.94	1.83	44	18.21	2.67	44	15.23	1.77	44	11.43	1.32	42	15.02	1.96	42	11.96	1.75	46	9.33	1.18	46

Table 3.12: Descriptive statistics for diaphyseal diameters, by sex

Sex	UMSAP			UMSML			USBAP			USBML			RMSAP			RMSML			CMSMX			CMSMN		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Female	10.99	1.15	158	13.75	1.68	158	16.72	2.33	158	13.98	1.42	158	10.36	1.10	156	13.73	1.60	156	10.88	1.38	166	8.37	1.00	166
Male	12.91	1.44	179	15.57	1.99	179	19.21	2.70	179	16.29	1.93	179	11.99	1.16	174	15.46	1.89	174	12.65	1.84	184	9.70	1.26	184

Sex	HMSAP			HMSML			TMSAP			TMSML			FMSAP			FMSML			FSTAP			FSTML		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Female	19.14	2.48	160	18.19	2.59	160	24.98	3.11	155	20.73	2.18	155	25.29	2.35	161	24.26	2.31	161	22.87	2.57	161	29.23	3.07	161
Male	21.34	2.34	181	20.82	2.49	181	27.51	3.09	179	23.12	2.53	179	28.71	2.88	184	26.62	2.79	184	25.36	2.94	184	31.95	3.63	184

Table 3.13: Summary of significant post-hoc tests on diaphyseal diameters by age

Age class	30-50	Over 50
Under 30	TMSAP * UMSAP * UMSML * USBAP * CMSMN * RMSAP * RMSML * HMSAP ** HMSML * FMSML ** FSTML **	UMSAP * CMSMN * FMSML ** FSTML **

** = p<.005, * = p<.05 Tamhane: UMSAP, USBAP, FMSML Tukey: All other variables

The one-way ANOVA shows significantly more between-group than within-group variance for all diaphyseal diameters by climate (Tables 3.14 and 3.15). All diameters are significantly different between hot and temperate climates, and most are also significantly different between hot and cold climates, including variables from all bones examined in the study. Four of the variables are significantly different between temperate and cold climates.

Table 3.14: Descriptive statistics for diaphyseal diameters by climate

	Hot			Temp.			Cold		
	Mean	S.D	N	Mean	S.D	N	Mean	S.D	N
TMSAP	25.38	3.52	125	26.78	3.21	141	27.14	2.76	58
TMSML	21.70	3.04	125	22.49	2.53	141	21.64	1.93	58
UMSAP	11.50	1.64	130	12.50	1.57	142	11.94	1.35	57
UMSML	13.95	2.13	130	15.57	1.93	142	14.47	1.35	57
USBAP	16.53	2.63	130	18.83	2.40	142	19.25	2.37	57
USBML	14.78	2.22	130	15.79	1.98	142	14.65	1.51	57
RMSAP	10.95	1.58	124	11.53	1.21	141	10.97	1.23	58
RMSML	13.77	2.11	124	15.19	1.71	141	15.22	1.50	58
HMSAP	19.09	2.87	128	20.89	2.17	146	21.59	2.10	59
HMSML	18.42	2.95	128	20.45	2.52	146	20.12	2.47	59
FMSAP	26.32	3.26	131	27.22	2.93	147	28.56	2.87	58
FMSML	24.09	2.96	131	26.55	2.40	147	26.29	2.19	58
FSTAP	23.01	3.27	131	24.72	2.56	147	25.69	2.69	58
FSTML	28.29	3.41	131	32.63	2.91	147	31.20	2.43	58

Table 3.15: Summary of significant (.05) post-hoc tests by climate

Climate	Temperate	Cold
Hot	TMSAP ** TMSLML * UMSAP ** UMSML ** USBAP ** USBML ** CMSMX ** CMSMN * RMSAP ** RMSML ** HMSAP ** HMSML ** FMSAP * FMSML ** FSTAP * FSTML **	TMSAP ** UMSAP ** UMSML ** USMAP ** CMSMX ** RMSML ** HMSAP ** HMSML ** FMSAP ** FMSML ** FSTAP ** FSTML **
Temperate		TMSML * FSTML ** USBML * FMSAP *

** = p<.005, * = p<.05 Tukey: TMSAP, UMSAP, USBAP, USBML, HMSML, FMSAP. All others Tamhane.

The one-way ANOVA results for lifestyle show that there is significantly more between-group than within-group variance for these categories (Table 3.10 and 3.16). The post-hoc tests reveal significant differences between all pairs of lifestyle categories except hunt/gather and hunt/fish (Table 3.17). The agriculturalists are perhaps the most unusual in their diaphyseal diameters, showing significant differences at the most skeletal locations when compared with hunt/gather people, hunt/fish people, and cultivate/hunt people. The hunt/herd people differ in most locations from the hunt/fish and cultivate/hunt people.

Table 3.16 : Descriptive statistics for diaphyseal diameters, by lifestyle

Continent	TMSAP			TMSML			UMSAP			UMSML			USBAP			USBML			CMSMX			CMSMN		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
hunt/fish	25.76	3.74	110	21.00	2.13	110	11.85	2.06	110	14.17	1.99	110	18.22	3.49	110	14.69	1.91	110	11.07	1.56	116	8.75	1.28	116
hunt/gather	25.82	3.94	30	21.17	3.39	30	11.94	2.48	30	13.83	2.30	30	16.93	3.47	30	14.61	2.65	30	11.54	1.91	30	8.92	1.74	30
hunt/herd	25.22	2.91	46	22.20	2.58	46	12.25	2.08	46	15.19	1.86	46	18.01	2.46	46	15.93	1.98	46	12.49	1.48	47	9.38	1.21	47
cultivate/hunt	27.47	3.22	80	22.18	2.56	80	12.01	1.22	80	14.44	1.42	80	17.95	2.06	80	14.99	1.51	80	11.27	1.36	84	8.75	.98	84
agriculture	26.54	2.67	88	23.09	2.62	88	12.39	1.43	89	15.68	2.22	89	18.01	2.59	89	15.82	2.30	89	12.87	2.15	93	9.61	1.42	93

	RMSAP			RMSML			HMSAP			HMSML			FMSAP			FMSML			FSTAP			FSTML			
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	
hunt/fish	10.80	1.50	108	14.33	1.98	108	19.99	3.02	113	19.55	3.45	113	26.82	3.37	114	26.82	3.37	114	24.67	3.19	114	23.67	3.52	114	29.51
hunt/gather	11.20	1.86	29	13.66	2.25	29	19.01	2.86	30	18.08	3.62	30	26.11	3.62	30	26.11	3.62	30	23.91	2.67	30	22.59	2.96	30	28.03
hunt/herd	11.30	1.34	45	15.52	1.70	45	20.84	2.22	46	19.31	2.13	46	26.69	2.88	45	26.69	2.88	45	26.68	2.96	45	24.10	2.39	45	31.54
cultivate/hunt	11.11	.99	78	13.94	1.38	78	19.53	1.77	80	19.63	2.02	80	27.00	2.88	83	27.00	2.88	83	25.17	2.31	83	23.50	2.32	83	31.20
agriculture	11.70	1.32	90	15.44	1.94	90	21.13	2.67	92	20.13	2.63	92	27.84	3.04	93	27.84	3.04	93	26.51	2.30	93	25.62	2.97	93	31.74

Table 3.17 : Summary of significant post-hoc test results for body shape by lifestyle

	Hunt/gather	Hunt/fish	Hunt/herd	Cultivate/hunt	Agriculture
Hunt/gather			RMSML *	FSTML **	UMSML **
			FMSML **		CMSMX *
			FSTML **		RMSML *
					HMSAP *
					FMSML **
					FSTAP **
					FSTML **
Hunt/fish			UMSML *	TMSAP **	TMSML **
			USBML **	TMSML **	UMSML **
			CMSMX **	FSTML *	CMSMX **
			CMSMN *		CMSMN **
			RMSML **		RMSAP **
			FMSML **		RMSML **
			FSTML *		HMSAP *
					FSTAP **
					FSTML **
Hunt/herd				TMSAP **	FSTAP *
				CMSMX **	
				CMSMN *	
				RMSML **	
				HMSAP *	
				FMSML *	
Cultivate/hunt					UMSML **
					CMSMX **
					CMSMN **
					RMSAP *
					RMSML **
					HMSAP **
					FSTAP **

** = p<.005, * = p<.05 All Tamhane test

The Asian continent shows the most significant differences in diaphyseal diameters with other continents, being the population with the smallest diaphyseal diameters (Table 3.19). The Australasian continent shows least significant differences with other continents, and where they do differ, they tend to have significantly thinner femoral diaphyses, except in comparison with the Asian continent (Table 3.18).

Table 3.18 : Descriptive statistics for diaphyseal diameters, by continent

Continent	TMSAP			TMSML			UMSAP			UMSML			USBAP			USBML			CMSMX			CMSMN		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Africa	26.41	2.94	65	22.19	3.29	65	11.90	1.69	68	14.53	2.24	68	16.83	2.64	68	15.15	2.41	68	12.38	2.07	69	9.39	1.49	69
Europe	25.48	2.83	81	22.50	2.46	81	12.22	1.63	79	15.49	2.14	79	17.97	2.11	79	15.67	2.06	79	12.71	1.93	83	9.35	1.24	83
Americas	27.74	2.88	129	21.99	2.21	129	12.29	1.42	131	14.77	1.60	131	19.17	2.39	131	15.11	1.69	131	11.24	1.35	137	8.89	1.09	137
Asia	22.43	2.91	34	20.36	2.71	34	10.63	1.52	36	13.49	2.28	36	15.87	3.26	36	14.24	2.15	36	10.69	1.74	36	8.33	1.37	36
Australasia	26.72	4.05	15	23.02	3.03	15	12.19	1.59	15	14.55	2.39	15	18.27	2.95	15	15.87	2.59	15	12.05	2.13	15	9.34	1.97	15

	RMSAP			RMSML			HMSAP			HMSML			FMSAP			FMSML			FSTAP			FSTML		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Africa	11.39	1.62	65	14.46	2.24	65	20.15	2.97	68	18.71	3.02	68	27.47	3.29	69	25.34	2.78	69	24.39	3.30	69	29.36	3.18	69
Europe	11.45	1.27	80	15.56	1.74	80	20.97	2.36	82	19.94	2.27	82	27.02	3.07	81	26.86	2.60	81	24.92	2.80	81	32.30	3.17	81
Americas	11.19	1.16	130	14.66	1.61	130	20.73	2.19	134	20.55	2.51	134	27.74	2.89	135	25.98	2.19	135	24.70	2.57	135	31.93	2.70	135
Asia	10.12	1.54	33	12.96	1.99	33	17.71	2.59	34	17.25	2.77	34	24.27	2.51	36	22.06	2.78	36	20.96	3.02	36	25.98	3.49	36
Australasia	11.62	1.48	15	14.27	2.04	15	19.77	2.92	15	18.86	3.60	15	26.85	3.00	15	23.78	2.40	15	23.15	2.31	15	28.21	2.52	15

Table 3.19: Summary of significant post-hoc tests for diaphyseal diameter by continent

	Europe	Americas	Asia	Australasia
Africa	UMSML *	TMSAP *	TMSAP ** TMSML *	
	HMSML *	USBAP **	UMSAP ** CMSMX **	
	RMSML *	CMSMX **	CMSMN ** RMSAP **	
	FMSML **	HMSML **	RMSML * HMSAP **	
	FSTML **	FSTML **	FMSAP ** FMSML **	
			FSTAP ** FSTML **	
Europe		TMSAP **	TMSAP ** TMSML **	FMSML **
		UMSML *	UMSAP ** UMSML **	FSTML **
		USBAP **	USBAP ** USBML **	
		CMSMX **	CMSMX ** CMSMN **	
		RMSML **	RMSAP ** RMSML **	
			HMSAP ** HMSML **	
			FMSAP ** FMSML **	
			FSTAP ** FSTML **	
Americas			TMSAP ** TMSML **	FMSML **
			UMSAP ** UMSML **	FSTML **
			USBAP ** CMSMN **	
			RMSAP ** RMSML **	
			HMSAP ** HMSML **	
			FMSAP ** FMSML **	
			FSTAP ** FSTML **	
Asia				TMSAP **
				UMSAP **
				RMSAP **
				FMSAP *
				FSTAP *
				FSTML *

** = p<.005, * = p<.05: TMSAP, UMSAP, HMSAP, HMSML, FMSAP, FMSML, FSTML
All others Tamhane

Population profiles

Similar patterns are shown in all diaphyseal diameters, when plotted by population, so only those for the femur and humerus are shown (Figures 3.2 and 3.3), since there are some interesting variations in the patterns between the upper and lower limbs. For both bones, the Small African sample and the Andaman population have

the lowest mean diaphyseal diameters. The Polynesian sample is low for both mean anterior-posterior and mediolateral measures of the humerus midshaft, but there is a large discrepancy between these values for the femur midshaft. The Polynesian femur midshaft anterior-posterior diameter is much larger than the mediolateral diameter (Figure 3.2). The populations with the highest mean diaphyseal dimensions for the femur include the Inuit and Sadlermiut and Japanese. The Egyptian and Kerma populations are high on the anterior-posterior diameter, but less extreme on the mediolateral diameter of the femur. For the humerus, the Inuit and Japanese again are among those populations with high means. The Terry and Prince Rupert Harbour populations also have high means, but the Sadlermiut, Kerma and Egyptian populations are low on mean humerus diameters.

The rest of the populations have intermediate mean values for humeral and femoral diameters, but there are subtle variations in the relationships between anterior-posterior and mediolateral diameters, and between the mean values for different bones. There is, however, considerable overlap between the boxplots for different populations, and sample sizes are small.

Figure 3.2: Boxplot of femur midshaft dimensions, by population

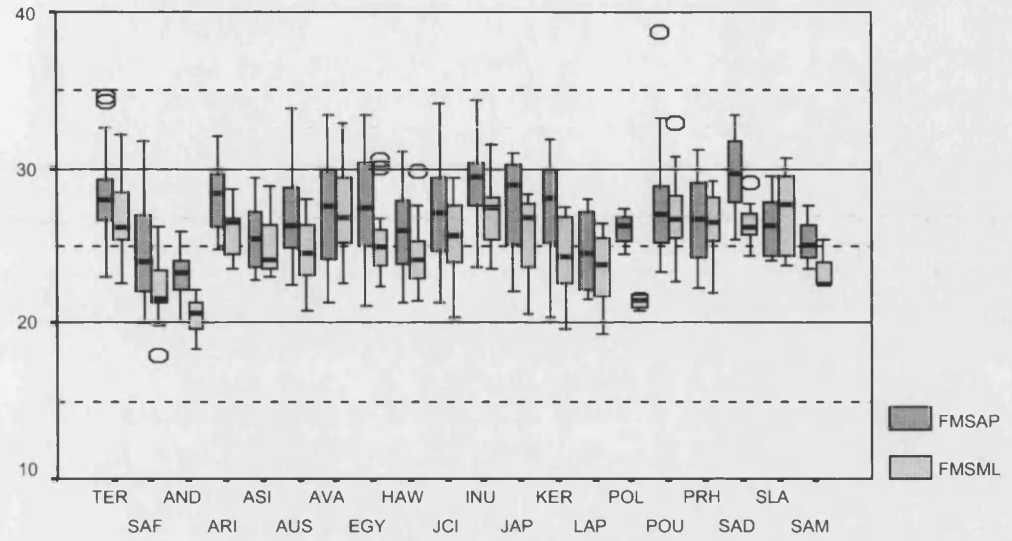
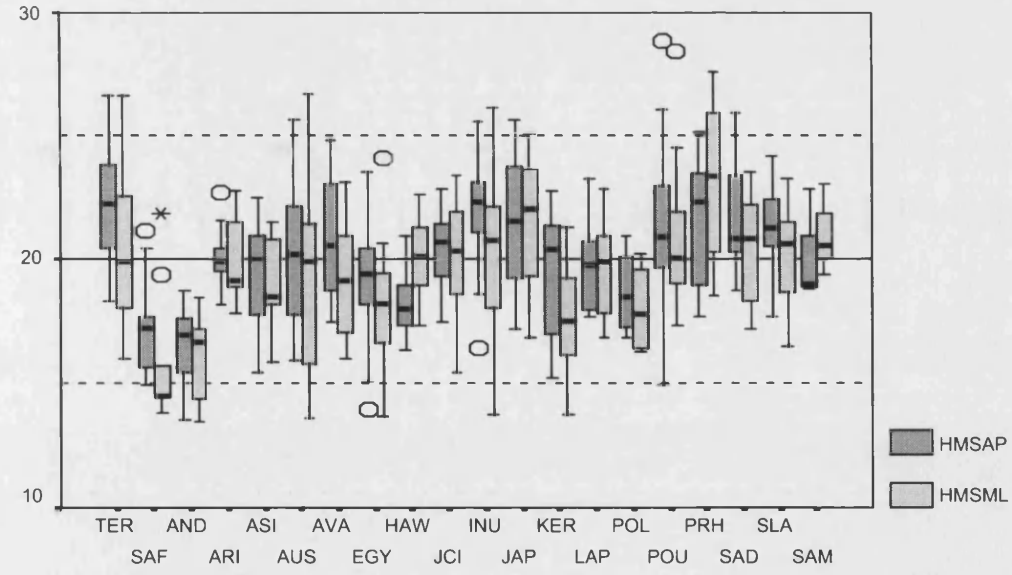


Figure 3.3: Boxplot of humerus midshaft dimensions, by population



Five-way ANOVA

If all other categories are held constant, sex is the only category that has a significant effect on all diaphyseal dimension variables. Lifestyle has a significant effect only on the two humerus midshaft dimensions, although significance is approached for some other variables (Table 3.20).

Table 3.20: Summary of five-way ANOVA results, diaphyseal diameters

	TMSAP					**TMSML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	1487.763	252			none	1102.835	252		
age	1718.627	292	0.997	**ns**	age	1213.271	292	0.949	**ns**
sex	2227.873	286	1.319	**0.05**	sex	1816.282	286	1.451	**0.01**
climate	1668.368	266	1.062	**ns**	climate	1150.972	266	0.989	**ns**
lifestyle	1752.571	276	1.076	**ns**	lifestyle	1345.116	276	1.114	**ns**
continent	1677.221	268	1.060	**ns**	continent	1296.151	268	1.105	**ns**

	CMSMX					**CMSMN**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	490.116	266			none	249.782	266		
age	554.262	307	0.980	**ns**	age	286.882	307	0.995	**ns**
sex	864.036	300	1.563	**0.01**	sex	457.515	300	1.624	**0.01**
climate	531.322	282	1.023	**ns**	climate	281.213	282	1.062	**ns**
lifestyle	575.347	292	1.069	**ns**	lifestyle	299.031	292	1.091	**ns**
continent	548.339	283	1.052	**ns**	continent	273.082	283	1.028	**ns**

	UMSAP					**UMSML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	276.796	255			none	521.249	255		
age	317.711	296	0.989	**ns**	age	607.011	296	1.003	**ns**
sex	613.038	289	1.954	**0.01**	sex	892.467	289	1.511	**0.01**
climate	322.858	271	1.098	**ns**	climate	615.349	271	1.111	**ns**
lifestyle	352.285	281	1.155	**ns**	lifestyle	697.121	281	1.214	**ns**
continent	328.672	272	1.113	**ns**	continent	577.694	272	1.039	**ns**

Table 3.20 cont.

	USBAP					**USBML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	915.444	255			none	542.783	255		
age	1008.002	296	0.949	**ns**	age	592.426	296	0.940	**ns**
sex	1434.996	289	1.383	**0.01**	sex	1080.529	289	1.757	**0.01**
climate	1008.983	271	1.037	**ns**	climate	624.458	271	1.083	**ns**
lifestyle	1114.05	281	1.104	**ns**	lifestyle	657.126	281	1.099	**ns**
continent	1083.024	272	1.109	**ns**	continent	602.286	272	1.040	**ns**

	RMSAP					**RMSML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	219.768	251			none	456.414	251		
age	246.804	291	0.969	**ns**	age	524.883	291	0.992	**ns**
sex	475.058	285	1.904	**0.01**	sex	748.301	285	1.444	**0.01**
climate	248.467	266	1.067	**ns**	climate	480.504	266	0.993	**ns**
lifestyle	258.576	275	1.074	**ns**	lifestyle	590.317	275	1.181	**ns**
continent	255.245	266	1.096	**ns**	continent	494.017	266	1.021	**ns**

	HMSAP					**HMSML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	788.184	260			none	911.436	260		
age	950.015	301	1.041	**ns**	age	995.925	301	0.944	**ns**
sex	1440.478	294	1.616	**0.01**	sex	1784.113	294	1.731	**0.01**
climate	862.543	275	1.035	**ns**	climate	1072.588	275	1.113	**ns**
lifestyle	1120.158	285	1.297	**0.05**	lifestyle	1303.66	285	1.305	**0.05**
continent	910.677	276	1.088	**ns**	continent	1079.868	276	1.116	**ns**

	FMSAP					**FMSML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	1252.07	262			none	871.578	262		
age	1450.886	303	1.002	**ns**	age	990.644	303	0.983	**ns**
sex	2370.161	296	1.676	**0.01**	sex	1453.941	296	1.477	**0.01**
climate	1430.739	278	1.077	**ns**	climate	992.485	278	1.073	**ns**
lifestyle	1557.139	288	1.131	**ns**	lifestyle	1115.046	288	1.164	**ns**
continent	1369.375	279	1.027	**ns**	continent	961.376	279	1.036	**ns**

	FSTAP					**FSTML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	1196.081	262			none	1219.226	262		
age	1361.249	303	0.984	**ns**	age	1475.184	303	1.046	**ns**
sex	1837.525	296	1.360	**0.01**	sex	2011.02	296	1.460	**0.01**
climate	1325.564	278	1.044	**ns**	climate	1504.989	278	1.163	**ns**
lifestyle	1590.972	288	1.210	**ns**	lifestyle	1593.191	288	1.189	**ns**
continent	1286.436	279	1.010	**ns**	continent	1443.849	279	1.112	**ns**

That lifestyle is a significant influence on humerus midshaft diameters even once sex has been held constant, may demonstrate that different subsistence strategies have differing requirements in terms of habitual arm activity patterns. However, as with the results for bone length, the results for diaphyseal diameters may be driven by body size differences between the populations represented in the data sets.

The interactions between categories for diaphyseal diameters follow a similar pattern to those for bone length (Table 3.21). Age interacts significantly with few other categories, the exception being for two of the femoral diaphyseal diameters where interactions between age and lifestyle or climate are significant, once all other categories are held constant. This suggests that femur diaphyseal diameter is influenced by age, but that the nature and degree of influence varies between climatic zones and lifestyles.

Most of the significant interactions are between sex and either climate, lifestyle or continent. This implies that sexual dimorphism in diaphyseal diameters varies between these categories. For the humerus diameters, it is the lifestyle and continent categories that mediate the difference in sexes, and for the ulna it is the climatic zone that affects sexual dimorphism. Sexual dimorphism in diameters of the tibia and radius are influenced only by continent. Climate and continent exhibit a significant interaction for clavicle minimum midshaft diameter. This means that any differences in clavicle diameter by climate do not remain stable across continents, such that clavicle diaphyseal morphology may be very different in populations otherwise exposed to the same climatic regime.

Table 3.21: Summary of significant interactions between categories for diaphyseal diameters

Significant interactions between two categories from four- and five-way ANOVA

Category excluded	age x sex	age x lifestyle	age x climate	age x continent	sex x lifestyle	sex x climate	sex x continent	lifestyle x climate	lifestyle x continent	climate x continent
None		FMSAP *	FSTML **		HMSAP ** HMSML **	UMSAP * USBML *	TMSML ** RMSML * HMSAP ** HMSML **			CMSMN *

* = $p < .05$, ** = $p < .01$

Epiphyseal dimensions

The joint surface dimensions are used in the calculation of epiphyseal robusticity, indices that evaluate joint size relative to element length. To allow accurate interpretation of these indices, the epiphyseal dimensions are investigated first.

One-way ANOVA

Very few epiphyseal dimensions show significant variation with age in the one -way ANOVA (Table 3.22), and have this result supported by post-hoc tests (Table 3.24). The only four to do so are the radial head diameter, the humerus head diameter, the humerus distal articular breath, and the ulna distal articular maximum breadth, which increase in size with age (Table 3.23). The other significant results in the ANOVA may indeed show greater between-group than within-group variation for the variables in question, but when age-classes are compared directly, no significant difference can be demonstrated.

Table 3.22: One-way ANOVA results for epiphyseal dimensions

	Age		Sex		Climate		Lifestyle		Continent	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
TPAAP	2.897	.035*	38.333	.000*	12.847	.000*	8.355	.000*	13.543	.000*
TPAML	1.933	.124	48.797	.000*	11.623	.000*	5.454	.000*	7.120	.000*
UDAMX	3.308	.021*	31.696	.000*	18.803	.000*	2.747	.029*	17.033	.000*
RHDIA	5.852	.001*	64.597	.000*	10.255	.000*	8.860	.000*	12.911	.000*
RDATB	2.305	.078	41.067	.000*	8.588	.000*	3.834	.005*	8.892	.000*
HDAB	3.525	.016*	43.080	.000*	8.724	.000*	4.295	.000*	9.552	.000*
HHDIA	4.119	.007*	57.687	.000*	26.554	.000*	6.005	.000*	13.463	.000*
FHDIA	2.486	.060	83.215	.000*	39.195	.000*	7.396	.000*	19.439	.000*
FLCL	2.868	.037*	50.764	.000*	4.444	.012*	4.239	.002*	11.580	.000*
FBCW	.781	.505	119.800	.000*	9.682	.000*	2.561	.038*	9.031	.000*

* = p< .05 For epiphyseal dimension codes, see table x.

Table 3.23: Descriptive statistics for epiphyseal dimensions by age category

Age Categ.	TPAAP			TPAML			UDAMX			RHDIA			RDATB		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Under 30	47.56	4.63	138	70.01	5.96	137	18.79	2.26	92	20.85	2.35	158	30.14	2.90	100
30 - 50	48.96	4.56	127	71.80	6.04	121	19.58	2.32	95	21.83	2.08	139	31.03	2.79	91
Over 50	48.51	4.72	37	70.70	5.94	37	20.17	1.73	22	21.94	2.33	43	31.43	2.52	24

	HHDIA			HDAB			FHDIA			FLCL			FBCW		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Under 30	41.66	4.61	161	41.22	4.11	113	42.95	4.30	160	60.12	6.09	160	69.90	6.69	151
30 - 50	43.12	4.14	142	42.41	3.95	103	43.96	4.13	145	61.32	6.07	145	70.94	6.51	140
Over 50	43.63	3.82	46	43.74	3.99	28	44.46	4.04	46	61.23	5.05	45	71.20	6.9	44

Table 3.24: Summary of significant post-hoc tests on epiphyseal dimensions by age

Age class	30-50	Over 50
Under 30	RHDIA **	UDAMX *
	HHDIA *	RHDIA *
		HDAB *
		HHDIA *

** = p<.005, * = p<.05 Tukey HSD test used in all cases.

Males show larger epiphyseal dimensions than females in all measurements (Table 3.25), which is statistically supported by one-way ANOVA (Table 3.22). Post-hoc test results are all significant to .000. This is due simply to the larger body size of males.

Table 3.25: Descriptive statistics for epiphyseal dimensions by sex

Sex	TPAAP			TPAML			UDAMX			RHDIA			RDATB		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Female	46.02	3.95	137	67.51	5.13	132	18.29	1.69	95	20.10	1.79	156	29.14	2.03	100
Male	50.25	4.28	156	73.67	5.31	155	20.35	2.27	107	22.55	2.02	174	32.17	2.76	108
	HHDIA			**HDAB**			**FHDIA**			**FLCL**			**FBCW**		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Female	40.18	3.61	160	39.86	3.10	112	40.97	3.09	161	57.69	4.49	160	66.01	4.55	153
Male	44.61	3.65	181	44.09	3.89	124	45.88	3.67	181	63.59	5.36	181	74.72	5.47	171

Although the one-way ANOVA for epiphyseal dimensions by climate reveals significant difference for all variables (Table 3.22), the post-hoc tests show that the significant differences are only between those from hot climates and either of the other two climate categories (Table 3.27). There are no significant differences between cold and temperate climates in terms of epiphyseal dimensions. This is also apparent from the comparison of the means for each climatic category (Table 3.26).

Table 3.26: Descriptive statistics for epiphyseal dimensions by climate

Climate	TPAAP			TPAML			UDAMX			RHDIA			RDATB		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
hot	46.82	4.79	138	69.12	6.29	139	18.40	2.34	103	20.78	2.59	144	29.88	2.91	106
temp.	49.61	4.32	122	72.64	5.68	116	20.37	1.76	63	21.97	1.82	145	31.45	2.71	66
cold	48.63	3.83	48	71.25	4.83	51	19.81	1.95	45	21.39	2.17	64	31.37	2.39	47

	HHDIA			HDAB			FHDIA			FLCL			FBCW		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
hot	40.65	4.67	149	40.93	4.23	115	41.42	4.07	151	59.80	6.81	151	68.64	6.92	137
temp.	44.04	3.78	149	43.34	3.53	76	44.89	3.74	150	61.49	5.25	149	71.91	6.44	145
cold	43.14	3.28	67	42.36	3.99	58	45.39	3.57	62	62.13	5.95	62	71.40	5.32	58

Table 3.27: Summary of significant (.05) post-hoc tests by climate

Climate	Temperate	Cold
Hot	TPAAP ** TPAML ** UDAMX ** RHDIA ** RDATB ** HDAB ** HHDIA ** FHDIA ** FCW **	TPAAP ** TPAML * UDAMX * RDATB ** HHDIA * FHDIA ** FLCL * FBCW *

** = p<.005, * = p<.05 Tukey: TPAAP, RDATB, HDAB, FBCW. All others Tamhane.

In general, the epiphyseal dimensions of those from hot climates are significantly smaller than those of individuals from temperate or cold climates. This may be due to the presence of the small San and Andaman samples in the hot climate category, but the cold-climate Inuit and Sadlermiut are also shorter than average, so there is further influence on epiphyseal dimensions than body size alone.

Epiphyseal dimensions also differ significantly with lifestyle (Table 3.22). The agricultural and hunt/fish lifestyles are the most different from one another (Table 3.28), with all ten measurements shown to be larger among agriculturalists (Table

3.29). In other paired comparisons, only a few variables differ significantly. The femoral head diameter (FHDIA) is significantly larger in the hunt/fish group than the hunt/gather group, but is significantly larger again among agriculturalists. The femoral head diameter is largest among the hunt/herd populations, and is significantly larger in this group than it is in the hunt/fish and cultivate/hunt groups.

The tibia plateau measurements (TPAAP and TPAML) also differ significantly between a number of pairs of lifestyle categories. Both dimensions are significantly larger among cultivate/hunt people than hunt/gather people, and hunt/fish people (Table 3.28). The agricultural group also have large tibia plateau dimensions (Table 3.29), and these are also significantly larger than those of the hunt/gather and hunt/fish people. The hunt/fish and hunt/herd people differ significantly in femoral head diameter, as discussed above, and also in their radial and humeral head diameters (RHDIA and HHDIA). In both cases, the hunt/herd people have the larger measurements. In all epiphyseal measurements, there are no significant differences between hunt/herd lifestyle strategies and agricultural or cultivate/hunt lifestyle strategies.

Table 3.28: Descriptive statistics for epiphyseal dimensions by lifestyle

Lifestyle	TPAAP			TPAML			UDAMX			RHDIA			RDATB		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
hunt/fish	46.55	4.81	85	69.04	5.58	88	18.82	2.76	83	20.55	2.31	108	30.22	3.18	87
hunt/gather	45.81	5.31	29	68.41	7.40	32	19.02	1.97	15	20.87	2.59	32	30.02	2.45	16
hunt/herd	48.65	4.69	35	71.82	6.42	31	19.27	1.07	5	22.22	2.31	45	31.44	2.86	6
cultiv./hunt	49.69	4.13	81	72.03	5.57	76	19.38	1.76	71	21.35	1.58	78	30.49	2.10	71
agriculture	49.16	3.77	78	72.18	5.57	79	20.27	1.91	37	22.16	2.27	90	32.17	2.96	39

	HHDIA			HDAB			FHDIA			FLCL			FBCW		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
hunt/fish	41.47	4.61	114	41.34	4.41	108	42.79	4.80	110	59.16	5.65	109	69.01	6.52	108
hunt/gather	40.87	5.66	34	41.99	4.38	18	41.40	4.40	33	63.17	9.50	33	70.07	8.55	18
hunt/herd	44.12	3.68	46	41.36	3.26	6	45.58	4.51	45	60.43	6.14	45	71.43	6.41	44
cultiv./hunt	42.49	3.82	80	41.76	3.09	77	43.18	3.19	83	61.57	4.86	83	70.61	6.44	79
agriculture	43.56	3.77	91	44.35	4.24	40	44.50	3.56	92	61.75	5.72	92	71.82	6.40	91

Table 3.29: Summary of significant post-hoc results for epiphyseal dimensions by lifestyle

	Hunt/herd	Cultivate/hunt	Agriculture
Hunt/gather	FHDIA **	TPAAP ** TPAML *	TPAAP ** FHDIA **
Hunt/fish	RHDIA ** HHDIA ** FHDIA **	TPAAP ** TPAML * FLCL * FHDIA *	TPAAP * TPAML ** UDAMX * RHDIA ** RDATB * HHDIA ** HDAB ** FHDIA * FLCL * FBW *
Hunt/herd			
Cultivate/hunt			RDATB * HDAB *

** = p<.005, * = p<.05 Tukey test: TPAAP, TPAML, FBCW. All others Tamhane

The Asian continent differs significantly from all other continents in almost all epiphyseal measurements (Table 3.22), but there are significant differences between some other pairs of continents. In general, the Asian group have smaller measurements at all skeletal locations than the other groups, but the Australian

group are not significantly different at seven of these locations (Table 3.30). Asia and Australasia differ significantly in only three upper body variables, the ulna distal maximum diameter (UDAMX), the radial head diameter (RHDIA), and the humerus distal articulation breadth (HDAB). The Australasian group mean is larger in all three cases.

The European continent differs significantly from the African and Australasian continent in femoral head diameter (FHDIA), due to the large femoral head among Europeans (Table 3.31). The American populations have significantly larger femoral lateral condyle lengths (FLCL) than those of the African or European continents. There are no significant differences in epiphyseal dimensions between African and Australasia.

Table 3.30: Descriptive statistics for epiphyseal dimensions by continent

Cont.	TPAAP			TPAML			UDAMX			RHDIA			RDATB		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Africa	48.37	4.54	70	71.28	6.60	71	19.49	2.18	42	21.86	2.68	73	31.59	3.01	39
Europe	48.07	4.17	65	70.88	5.58	61	19.52	1.30	12	22.03	2.11	84	31.59	2.36	15
Americas	49.74	4.00	117	72.20	5.32	116	19.97	1.94	110	21.38	1.82	136	31.02	2.52	113
Asia	44.04	4.95	41	66.87	6.01	42	16.80	2.13	35	19.31	2.22	43	28.40	2.90	37
Austral.	47.47	4.00	15	68.72	5.91	16	19.35	1.87	12	21.32	1.95	17	30.36	2.28	15

	HHDIA			HDAB			FHDIA			FLCL			FBCW		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Africa	42.18	4.81	77	43.18	4.62	43	43.04	3.95	77	62.76	6.78	77	71.62	6.56	64
Europe	43.92	3.75	85	42.73	3.33	16	45.09	4.19	84	59.85	5.32	84	71.31	6.29	84
Americas	43.12	3.68	142	42.51	3.72	134	44.42	3.50	139	62.10	4.50	138	71.23	6.18	134
Asia	38.64	4.81	44	38.57	3.41	39	39.39	4.33	46	56.26	7.98	46	65.00	5.60	41
Austral.	41.55	3.45	17	42.24	3.99	17	41.98	3.28	17	60.42	5.45	17	69.91	8.40	17

Table 3.31: Summary of significant post-hoc results for epiphyseal dimensions by continent

	Europe	Americas	Asia	Australasia
Africa	FHDIA **	FLCL *	TPAAP ** TPAML ** UDAMX ** RHDIA ** RDATB ** HHDIA ** HDAB ** FLCL ** FHDIA ** FBCW **	
Europe		FLCL *	TPAAP ** TPAML ** UDAMX ** RDATB ** RHDIA ** HHDIA ** HDAB ** FHDIA ** FBCW **	FHDIA *
Americas			TPAAP ** TPAML ** UDAMX ** RDATB ** RHDIA ** HHDIA ** HDAB ** FLCL ** FHDIA ** FBCW **	
Asia				UDAMX ** RHDIA * HDAB *

** = p<.005, * = p<.05 Tamhane test: RHDIA, HHDIA, FLCL. All others Tukey test.

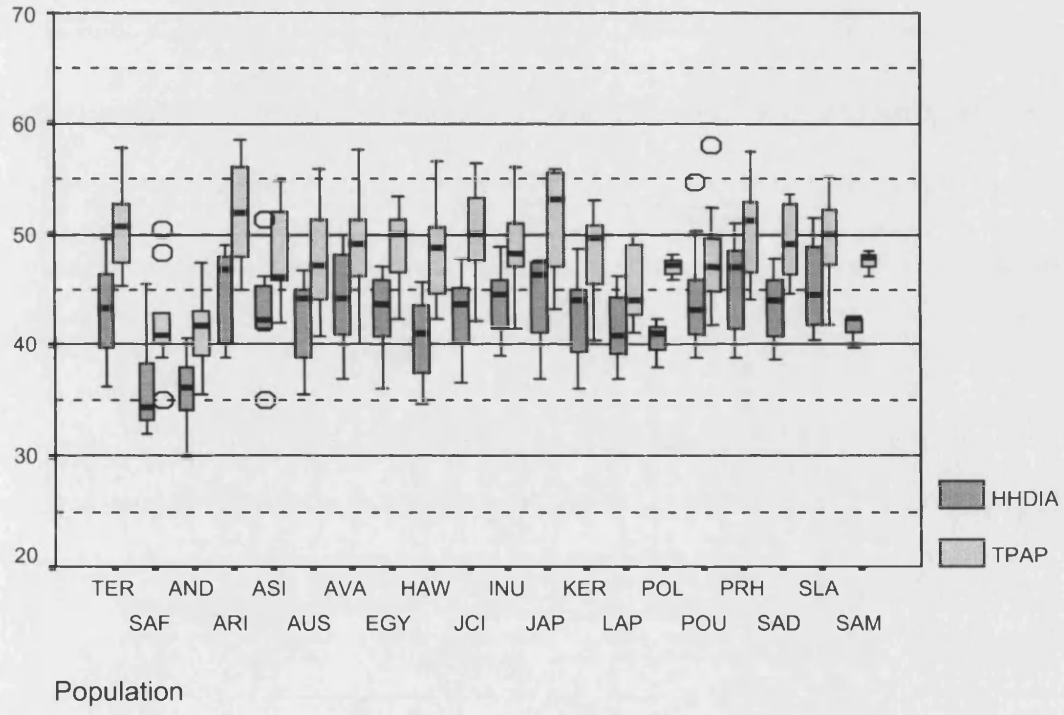
Population Summary

As with the plots for the bone length and diaphyseal diameters, there is little difference in the pattern of population-specific means between different epiphyseal dimensions. Body size differences overwhelm any more subtle patterns, so only a single plot, incorporating the humerus head diameter and the anterior-posterior diameter of the tibia plateau, is presented (Figure 3.4).

The Small African and Andaman populations are again those with the lowest means, while the Terry, Arikara, Japanese and Prince Rupert Harbour individuals are those with the highest means at both locations. Of these four, only the Terry population

have high stature as measured by long bone lengths. The rest are notably intermediate. The results for the epiphyseal robusticity indices, that take element length into consideration, will expand upon this finding and others, in order to investigate epiphyseal size in an appropriately independent way.

Figure 3.4: Boxplots of humerus head diameter and tibia plateau anterior-posterior diameter, by population



Five-way ANOVA

The same pattern of significance is seen for epiphyseal dimensions as for diaphyseal diameters. Only sex has a significant influence on all variables, when the influence of

other categories is held stable (Table 3.32). Lifestyle is the second most influential category, but shows significance only in the humeral articular surfaces.

Table 3.32: Summary of five-way ANOVA results, epiphyseal dimensions

	TPAP					**TPML**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	2262.172	218			none	3852.398	210		
age	2582.42	257	0.968	**ns**	age	4240.217	248	0.932	**ns**
sex	3702.77	251	1.422	**0.01**	sex	6852.577	242	1.544	**0.01**
climate	2575.874	232	1.070	**ns**	climate	4300.59	223	1.051	**ns**
lifestyle	2909.271	241	1.163	**ns**	lifestyle	4632.362	233	1.084	**ns**
continent	2600.831	234	1.071	**ns**	continent	4237.537	226	1.022	**ns**

	RHDIA					**HHDIA**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	538.515	251			none	1892.93	259		
age	636.685	291	1.020	**ns**	age	2196.616	300	1.002	**ns**
sex	1117.089	285	1.827	**0.01**	sex	4088.865	293	1.909	**0.01**
climate	628.268	266	1.101	**ns**	climate	2170.096	274	1.084	**ns**
lifestyle	644.07	275	1.092	**ns**	lifestyle	2584.869	284	1.245	**0.05**
continent	635.507	266	1.114	**ns**	continent	2207.262	275	1.098	**ns**

	HTHB					**FHDIA**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	1845.504	257			none	1452.471	261		
age	2196.054	298	1.026	**ns**	age	1669.9	302	0.994	**ns**
sex	3823.083	291	1.830	**0.01**	sex	3590.311	295	2.187	**0.01**
climate	2033.972	272	1.041	**ns**	climate	1612.236	277	1.046	**ns**
lifestyle	2558.059	282	1.263	**0.05**	lifestyle	1868.104	287	1.170	**ns**
continent	2083.51	273	1.063	**ns**	continent	1599.457	278	1.034	**ns**

	FLCL					**FBCW**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	3874.331	261			none	4379.575	253		
age	4319.63	301	0.967	**ns**	age	5194.74	290	1.035	**ns**
sex	6944.358	295	1.586	**0.01**	sex	10958.56	285	2.221	**0.01**
climate	4458.014	276	1.088	**ns**	climate	4854.325	267	1.050	**ns**
lifestyle	4473.118	286	1.054	**ns**	lifestyle	5138.564	274	1.083	**ns**
continent	4457.926	278	1.080	**ns**	continent	4755.939	266	1.033	**ns**

All but one of the significant interactions for epiphyseal dimensions involve the category sex (Table 3.33). Sex interacts significantly with age for the radial head diameter, showing either that sexual dimorphism in this feature is affected by age, or that age-related differences in radial head diameter are mediated by sex. Sex interacts significantly with lifestyle category in influencing the humerus head diameter and humerus distal articular breadth. Sex and lifestyle have been shown to influence other aspects of humeral morphology. The degree to which there is sexual division of labour, and the form that labour would take is determined by the lifestyle category. The humerus is clearly especially sensitive to these lifestyle differences.

Sex and climate interact significantly for the radius and humeral heads, and for the humerus distal articulation breadth. Climate can influence epiphyseal dimensions through selection for body shape and proportions, and also through its effect on the possible subsistence regimes in a climatic zone. The humerus epiphyses are also influenced by an interaction between sex and continent, which affects the tibia plateau and femur lateral condyle length as well. Continent is not independent of climate or lifestyle, but may also stand for ethnic heritage. This significant interaction between sex and continent may highlight ethnic differences in sexual dimorphism of epiphyseal dimensions. It may alternatively be expressing differences in the degree of sexual dimorphism that can be traced to lifestyle or climatic factors.

Table 3.33 : Summary of significant interactions between categories for epiphyseal diameters

Significant interactions between two categories from four- and five-way ANOVA

Category excluded	age x sex	age x lifestyle	age x climate	age x continent	sex x lifestyle	sex x climate	sex x continent	lifestyle x climate	lifestyle x continent	climate x continent
None	RHDIA **				HHDIA ** HDAB **	RHDIA * HHDIA * HDAB *	TPAP * TPML * HHDIA ** HDAB ** FLCL **			FLCL **

* = p < .05, ** = p < .01

Body Shape Indices

An exploration of three indices is presented here, selected to represent the relative length of the lower limb bones (crural index), the relative length of the upper limb bones (brachial index), and the width of the torso relative to the forearm (claviculo-radial index). The formulae for these indices are listed in Chapter 2.

Table 3.34: Body shape indices by age, sex, climate, lifestyle and continent

	Claviculo-radial index	Crural index	Brachial index
Age			
Under 30	.62	.80	.74
30 - 50	.64	.80	.74
Over 50	.65	.79	.72
Sex			
Female	.63	.80	.72
Male	.63	.80	.74
Lifestyle			
hunt/fish	.64	.79	.72
hunt/gather	.61	.81	.75
hunt/herd	.62	.80	.73
cultivate/hunt	.63	.81	.75
agriculture	.64	.80	.73
Climate			
hot	.61	.81	.75
temperate	.63	.80	.74
cold	.67	.78	.69
Continent			
Africa	.63	.81	.75
Europe	.63	.79	.73
Americas	.66	.80	.72
Asia	.56	.81	.77
Australasia	.58	.81	.75
Total	**.63**	**.80**	**.73**

One-way ANOVA

Table 3.35: One-way ANOVAs for body shape indices

	Age		Sex		Climate		Lifestyle		Continent	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Brachial index	2.305	.077	12.945	.000*	44.777	.000*	4.194	.002*	11.852	.000*
Crural index	.621	.602	1.335	.265	17.872	.000*	4.613	.001*	2.345	.054
Claviculo-radial index	4.766	.003*	6.789	.001*	39.061	.000*	1.790	.130	40.293	.000*

* = p< 0.05

Neither brachial or crural indices are significantly different between age categories, but between group variance is more significant than within group variance for the claviculo-radial index (Table 3.35). However, post-hoc tests on the ANOVA result reveal support for this result only between age categories 1 and 3 (Tamhane p = 0.002). The claviculo-radial index mean increases in successive age categories, being lowest in category 1 and highest in category 3. This implies that torso width increases relative to forearm length throughout life, even in full adulthood. This is unsurprising, given the late completion of ossification in the clavicle.

Brachial index and claviculoradial index differ significantly between sexes, (Table 3.34) although post-hoc tests support a significant difference between males and females only in brachial index (Tamhane p = 0.00). Neither claviculo-radial index nor crural index is significantly different between males and females.

All three indices vary significantly with climate. Populations native to warm climates show relatively longer distal limbs and narrower torso than populations native to temperate climates, who are themselves significantly different to those from hot climates in the same way. The Tamhane post-hoc test supports these findings between all climate categories (Tukey and Tamhane significance $p < .005$), with the single exception of crural index between hot and temperate climates, which approaches significance at $p = 0.066$. This pattern follows Bergman's and Allen's rules of body form, as widely reported for humans, and establishes that the sampled populations are typical in their physiological response to climate.

Claviculo-radial index does not vary between the five categories of lifestyle (subsistence strategy), either in the ANOVA (Table 3.34) or in post-hoc tests. However, both crural index and brachial index do, although the post-hoc tests support this only between certain lifestyle categories (Table 3.36). The hunt/gather strategy is associated with significantly different brachial indices to those of hunt/fish and hunt/herd lifestyles, and significantly different crural indices to those of hunt/fish lifestyles. The cultivate/hunt lifestyle shows significantly different crural indices to those of hunt/fish lifestyles, and significantly different brachial indices to those of hunt/fish and hunt/herd lifestyles. Interaction between climate and lifestyle, as described below, provides an explanation for this finding. The hunt/fish and hunt/herd lifestyles are found predominantly in colder climates than the hunt/gather lifestyle, with the exception of the Andaman Islanders.

Table 3.36: Summary of significant post-hoc test results for body shape by lifestyle

	Hunt/gather	Hunt/fish	Hunt/herd	Cultivate/hunt	Agriculture
Hunt/gather		CI p= 0.006 BI p= 0.034	BI p= 0.031		
Hunt/fish				CI p= 0.017 BI p= 0.002	
Hunt/herd				BI p= 0.001	

Tamhane test: CI = Crural index; BI = Brachial index

All three indices vary significantly between certain pairs of continents (Table 3.37), although the one-way ANOVA showed significant differences only for brachial and claviculo-radial index (Table 3.34). Asia and Australasia are not distinguishable in any index, but Asia is significantly different to all other continental categories in all three indices. African and Australasian populations are significantly different in claviculo-radial index, despite both being characterised in this sample by populations exclusively from hot climates.

Table 3.37: Summary of significant post-hoc results for body shape by continent

	Africa	**Europe**	**Americas**	**Asia**	**Australasia**
Africa		CI p= .003	CRI p= .000 CI p= .003 BI p= .000	CRI p= .000 CI p= .024 BI p= .001	CRI p= .005
Europe			CRI p= .000	CRI p= .000 CI p= .000 BI p=.000	CRI p= .003
Americas				CRI p= .000 CI p= .000 BI p= .000	CRI p= .000 BI p= 006
Asia					

Tukey HSD: CRI = Claviculoradial index Tamhane: CI = Crural index BI = Brachial index

Between-group differences in brachial and crural indices are likely to be due to differences in the distal limb segments rather than the proximal limb segments. The greater variability in distal limb segments was demonstrated by Holliday and Ruff (2001). It has further been demonstrated above that the tibia, ulna and radius are the only long bones to show significant effects of climate.

Population Summary

Brachial index is relatively stable across all populations, with mean values falling between .7 and .8 (Figure 3.5). The lower means, under .7, belong to the cold climate Inuit, Lapp and Sadlermiut populations. The Poundbury population demonstrate the most variance in brachial index. Crural index is also stable around the mean of .8 (Figure 3.6). The Sadlermiut, Japanese and Lapp populations are particularly low, relative to other populations. The Kerma, Polynesians, Arikara and Hawikuh are positioned relatively high in relation to crural indices of other populations. The populations of Arikara, Hawikuh and Jersey County, Illinois show the greatest variance in crural index.

Figure 3.5 : Boxplot of brachial index by population

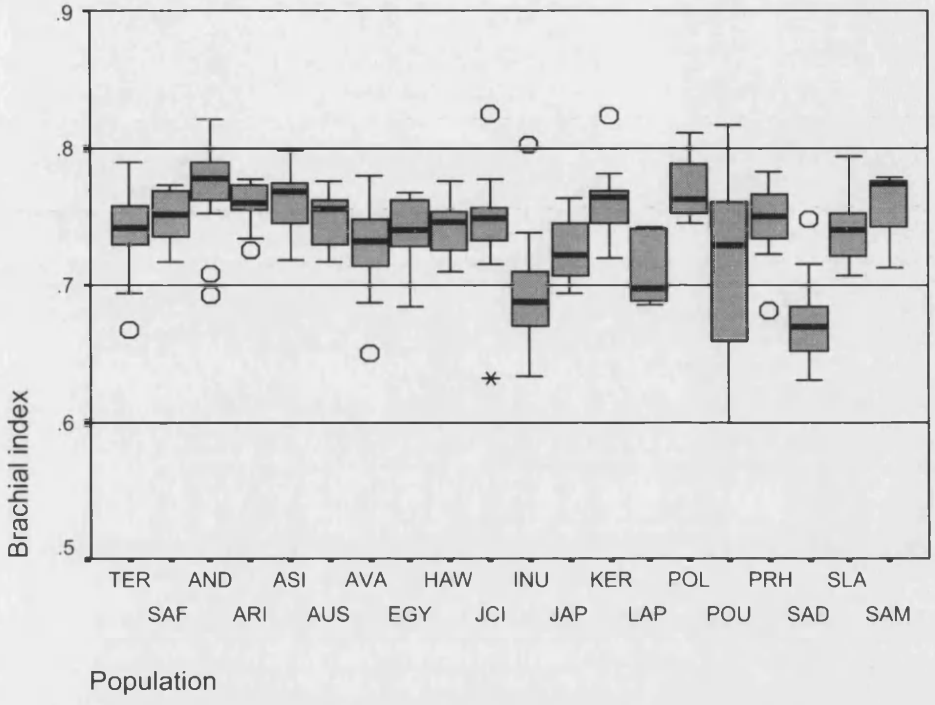
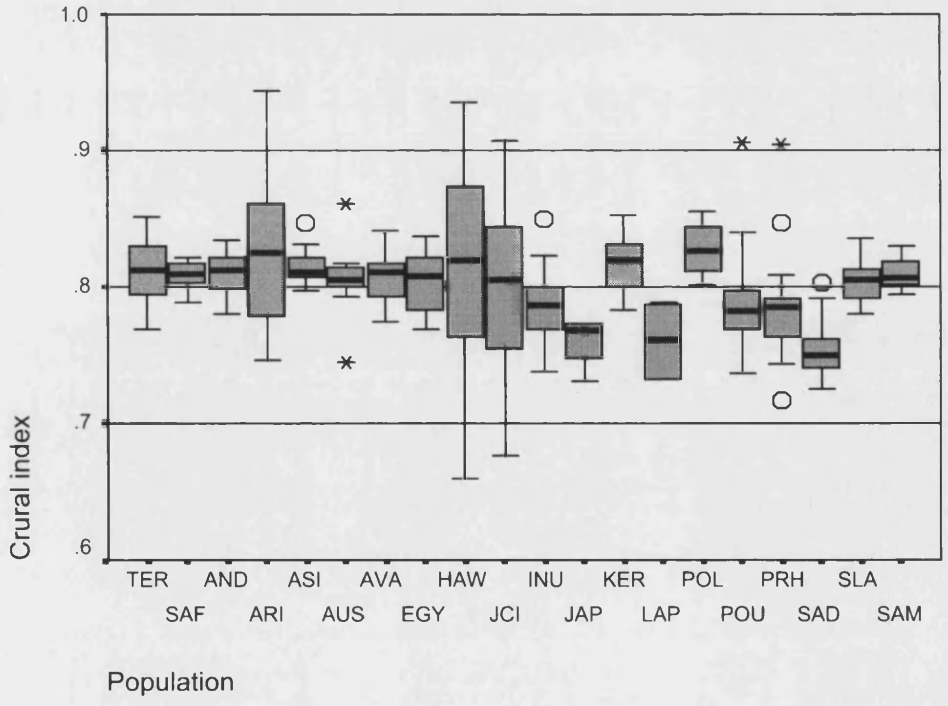
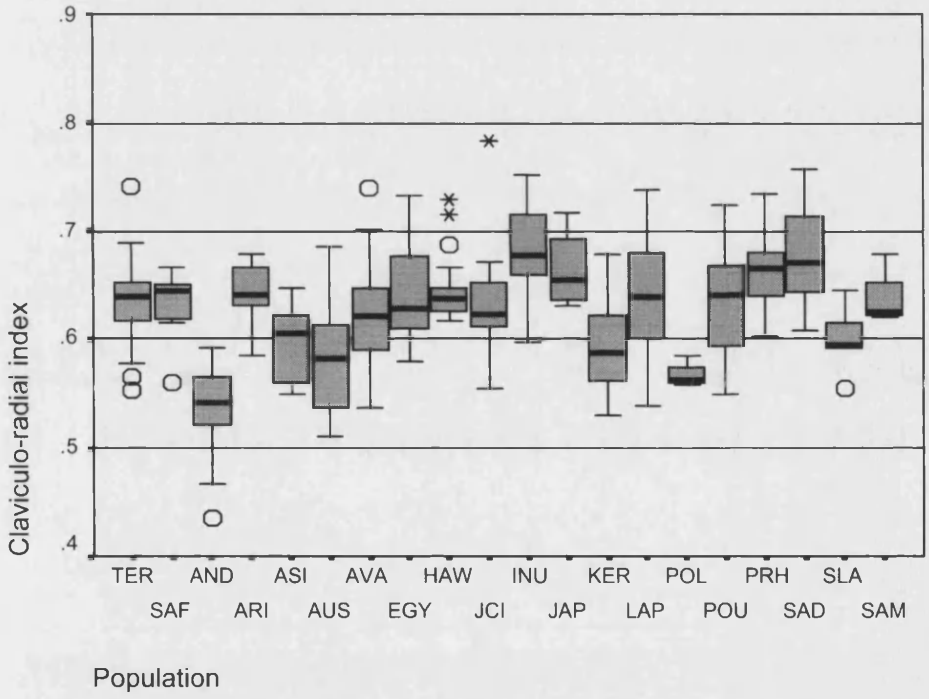


Figure 3.6: Boxplot of crural index by population



The claviculo-radial index is more variable than the other two body shape indices (Figure 3.7). The Andamanese, Kerma, Polynesian and Australian populations have low mean claviculo-radial indices, under .6. The Inuit, Sadlermiut, Japanese and Prince Rupert Harbour populations have high claviculo-radial indices, over .65. The high indices are colder climate populations, and may be driven by short radii, rather than long clavicles.

Figure 3.7: Boxplot of claviculo-radial index by population



Five-way ANOVA

None of the body shape indices show any significant influences from age, sex, climate, lifestyle or continent, when variation in all other categories is held constant (Table 3.38). This implies that human body proportions as measured by these

indices remain stable over all these categories. The clear influence of sex and lifestyle demonstrated for long bone length is cancelled out by the calculation of body shape indices.

The absence of a significant climatic effect is particularly interesting, since the relative reduction of distal limb lengths in cold climates is repeatedly reported. Indeed, when climate alone is examined, such effects are notable and statistically significant. However, such effects must be restricted to particular comparisons between groups of populations. For example, the cold climates are represented only by hunt/fish and hunt/herd populations, and just three major populations from two restricted geographical regions, the Inuit, Sadlermiut and Lapp. Although these populations may well demonstrate reduced distal limbs (Figures 3.5 and 3.6), the variability of climate as a variable does not match the variability of the brachial and crural indices. The findings here highlight the danger in taking particular populations, with their own special traits, as representatives of a whole category, such as climate or lifestyle.

There are no significant interactions between categories for claviculo-radial index, or crural index. This means that variation within each category is random with respect to variation in the other categories for these indices. For brachial index, the only significant interaction is between sex and lifestyle ($p = .009$). Any sex-based difference in the relative length of the radius to the humerus are therefore altered by the lifestyle category.

Table 3.21 : Summary of five-way ANOVA results, body shape indices

Brachial Index

category excluded	SS	df	F	sig.
none	0.321	250		
age	0.350	290	0.939951	ns
sex	0.429	284	1.176451	ns
climate	0.378	265	1.110915	ns
lifestyle	0.372	274	1.057371	ns
continent	0.331	265	0.972786	ns

Crural Index

category excluded	SS	df	F	sig.
none	0.310	250		
age	0.352	290	0.978865	ns
sex	0.364	284	1.033621	ns
climate	0.335	264	1.023338	ns
lifestyle	0.360	274	1.059571	ns
continent	0.332	266	1.006549	ns

Claviculo-radial Index

category excluded	SS	df	F	sig.
none	0.404	251		
age	0.472	291	1.007723	ns
sex	0.454	285	0.989699	ns
climate	0.436	266	1.01835	ns
lifestyle	0.472	275	1.066355	ns
continent	0.455	266	1.062728	ns

Diaphysis Robusticity

Variations in the diaphyseal robusticity at multiple points along the long bones in this study are analysed using one-way and multi-way ANOVA. Robusticity indices are calculated using bone length and diaphyseal diameters, and so these results will be interpreted in the context of the results for these variables, summarised above.

Table 3.39: One-way ANOVAs for diaphyseal robusticity

	Age		Sex		Climate		Lifestyle		Continent	
Variable	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Tibia midshaft robusticity	1.404	.241	14.731	.000*	41.835	.000*	3.260	.012*	23.847	.000*
Radius midshaft robusticity	2.762	.042*	7.199	.001*	66.586	.000*	13.895	.000*	11.739	.000*
Ulna midshaft robusticity	3.909	.009*	12.772	.000*	48.501	.000*	6.537	.000*	10.829	.000*
Ulna sub-brachial robusticity	1.446	.229	13.599	.000*	62.242	.000*	6.881	.000*	15.859	.000*
Clavicle mean robusticity	.012	.998	21.900	.000*	.717	.489	14.713	.000*	20.760	.000*
Humerus deltoid robusticity	2.916	.034*	20.318	.000*	40.075	.000*	10.202	.000*	11.503	.000*
Humerus midshaft robusticity	2.812	.039*	19.101	.000*	54.962	.000*	8.621	.000*	16.438	.000*
Femur midshaft robusticity	4.657	.003*	19.961	.000*	67.818	.000*	7.056	.000*	25.033	.000*
Femur sub-trochanter robusticity	5.473	.001*	7.981	.000*	106.47	.000*	8.513	.000*	49.564	.000*

* = p< 0.05

Robusticity indices calculated at tibia midshaft, ulna sub-brachial and clavicle midshaft positions show no significant difference with age, a result supported in full by Tamhane post-hoc tests. Although the remaining indices show significant difference using ANOVA, post-hoc tests do not support this in all cases. No post-hoc

tests (Tukey HSD or Tamhane) support significant difference between age classes for radius midshaft and ulna midshaft robusticity, despite significant ANOVA results. This indicates that although there may be general variance differences between groups, no two groups differ significantly in their average values. True significant differences in robusticity between age classes are only noted in the proximal limb elements, the humerus and femur, and then only between certain age classes (Table 3.41). In both positions in the humerus, diaphyseal robusticity increases from young adulthood into middle age only. In both positions in the femur, diaphyseal robusticity increases from young adulthood into middle age, and continues to increase into older age (Table 3.40).

Table 3.40: Descriptive statistics for diaphyseal robusticity by age

Age	Under 30			30 - 50			Over 50			Total		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TMSRI	14.19	1.24	154	14.40	1.15	127	14.47	1.16	43	14.31	1.19	324
RMSRI	11.59	1.23	152	11.89	1.31	129	12.13	1.48	42	11.78	1.31	323
UMSRI	11.87	1.29	153	12.17	1.24	132	12.38	1.39	44	12.06	1.29	329
USBRI	14.78	1.73	153	15.13	1.87	132	15.16	1.82	44	14.97	1.80	329
CMSRI	15.13	1.83	157	15.09	1.77	137	15.08	1.85	46	15.10	1.80	340
HMSRI	13.10	1.35	156	13.52	1.35	132	13.45	1.35	45	13.32	1.36	333
FMSRI	12.28	.94	155	12.61	.81	135	12.65	.91	46	12.46	.90	336
FSTRI	12.76	1.17	155	13.18	1.08	135	13.32	1.06	46	13.00	1.14	336

Table 3.41: Summary of significant post-hoc tests on diaphyseal robusticity by age

Age class	30-50	Over 50
Under 30	Humerus deltoid * Humerus midshaft * Femur midshaft ** Femur sub-troch. **	Femur midshaft * Femur sub-troch. *

** = p<.005, * = p<.05 Tamhane

All diaphyseal robusticity indices vary significantly by sex (Table 3.39), in both the

one-way ANOVA, and post-hoc tests (Tamhane test used for all except clavicle, in which Tukey HSD test used). The post-hoc test results between males and females range between p = 0.000 to p = 0.008. Between either sex and the unknown sex category, post-hoc test results range between p = 0.018 and p = 0.022. Males are more robust than females at all positions along the diaphyses analysed (Table 3.42).

Table 3.42: Descriptive statistics for diaphyseal robusticity by sex

	Female			Male			Total		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TMSRI	13.93	1.14	151	14.64	1.14	173	14.31	1.19	324
RMSRI	11.49	1.30	153	12.04	1.26	170	11.78	1.31	323
UMSRI	11.66	1.27	155	12.41	1.22	174	12.06	1.29	329
USBRI	14.45	1.68	155	15.44	1.78	174	14.97	1.80	329
CMSRI	14.45	1.44	162	15.70	1.89	178	15.10	1.80	340
HMSRI	12.86	1.30	157	13.72	1.29	176	13.32	1.36	333
FMSRI	12.15	.84	158	12.74	.86	178	12.46	.90	336
FSTRI	12.78	1.08	158	13.20	1.16	178	13.00	1.14	336

All diaphyseal indices except clavicle midshaft robusticity vary significantly by climate (Table 3.39). In the main, the post-hoc tests support this finding very strongly (Table 3.44) between all climatic categories. This in turn supports the findings of Pearson (2000), who showed that climate is a strong influence on diaphyseal robusticity. For all indices except clavicle robusticity, robusticity increases with decreasing temperature (Table 3.43).

Table 3.43: Summary of diaphyseal robusticity by climate

Variable	Hot			Temperate			Cold		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TMSRI	13.73	1.14	146	14.49	1.06	145	15.14	1.00	67
RMSRI	11.08	1.12	144	11.90	1.05	145	12.97	1.19	64
UMSRI	11.39	1.19	148	12.39	1.19	146	13.01	1.23	63
USBRI	13.98	1.56	148	15.27	1.52	146	16.57	1.88	63
CMSRI	15.17	1.92	152	15.21	1.80	154	14.91	1.38	68
HMSRI	12.58	1.22	149	13.55	1.24	150	14.31	.95	66
FMSRI	11.91	.79	151	12.63	.79	151	13.18	.74	66
FSTRI	12.12	.97	151	13.47	.94	151	13.69	.77	66

Table 3.44: Summary of significant post-hoc tests by climate

Climate	Temperate	Cold
Hot	TM = .000 RM = .000 UM = .000 US = .000 HD = .000 HM = .000 FM = .000 FS = .000	TM = .000 RM = .000 UM = .000 US = .000 HD = .000 HM = .000 FM = .000 FS = .000
Temperate		TM = .000 RM = .000 UM = .003 US = .000 HD = .001 HM = .000 FM = .000 FS = .000

Tukey HSD test: CM = clavicle midshaft (Not significant), HD = humerus deltoid.
Tamhane test: TM = tibia midshaft, RM = radius midshaft, UM = ulna midshaft, US = ulna sub-brachial, HM = humerus midshaft, FM = femur midshaft, FS = femur sub-trochanter.

All diaphyseal robusticity indices vary significantly by lifestyle, according to the one-way ANOVA (Table 3.39). However, the post-hoc tests support significance only between certain categories (Table 3.46). There are no significant robusticity differences between the hunt and fishing lifestyle and agricultural lifestyle, nor between the hunt and herd and agricultural lifestyles. The hunt/fish and hunt/herd lifestyles differ significantly only in humerus deltoid robusticity, the hunt/fish people being more robust at the deltoid, although interestingly, not at midshaft. This may be

connected to the hypertrophic development of the deltoid noted in rowing populations (Laughlin et al., 1991, Weiss, 2003).

Agriculturalists are significantly more robust than cultivating and hunting people in all indices except the tibia midshaft index and the ulna sub-brachial index (Tables 3.45 and 3.46). People of the hunt/gather lifestyle have significantly less robust femora at midshaft and sub-trochanteric levels than those of the hunt/herd or agricultural lifestyle. They are also significantly less robust in the femur sub-trochanter region and more robust in the clavicle compared to the cultivate/hunt people. Hunt/herd people and cultivate/hunt people differ significantly in the radius and clavicle midshaft values. The cultivate/hunt people are the least robust in both regions.

Table 3.45: Summary of diaphyseal robusticity by lifestyle

	hunt/fish			hunt/gather			hunt/herd			cultivate/hunt			agriculture		
Variable	**Mean**	**S.D.**	**N**	**Mean**	**S.D.**	**N**	**Mean**	**S.D.**	**N**	**Mean**	**S.D.**	**N**	**Mean**	**S.D.**	**N**
TMSRI	14.52	1.23	110	13.81	1.29	34	14.00	1.17	46	14.30	1.22	80	14.37	1.07	88
RMSRI	12.11	1.49	108	11.32	1.39	32	12.10	1.19	45	10.96	.79	78	12.02	1.06	90
UMSRI	12.35	1.46	110	11.71	1.59	32	12.13	1.46	46	11.52	.91	80	12.36	1.21	89
USBRI	15.62	2.04	110	14.34	2.16	32	15.02	1.88	46	14.36	1.30	80	14.91	1.69	89
CMSRI	15.21	1.58	116	15.24	1.78	34	15.96	1.55	47	14.00	1.37	84	15.62	1.98	93
HMSRI	13.76	1.50	113	12.63	1.49	34	13.17	1.15	46	12.83	.92	80	13.41	1.30	92
FMSRI	12.63	1.06	114	11.88	.80	33	12.53	.76	45	12.18	.82	83	12.57	.79	93
FSTRI	13.04	1.31	114	12.02	1.07	33	13.09	.91	45	12.78	.98	83	13.28	1.07	93

Table 3.46: Summary of significant post-hoc tests by lifestyle

Lifestyle	Hunt/gather	Hunt/herd	Cultivate/hunt	Agriculture
Hunt/fish	TM p= .018 US p= .044 HD p= .000 HM p= .003 FM p= .000 FS p= .000	HD p= .005	RM p= .000 UM p= .000 US p= .000 CM p= .000 HD p= .000 HM p= .000 FM p= .008	
Hunt/gather		FM p= .006 FS p= .000	CM p= .002 FS p= .009	FM p= .001 FS p= .000
Hunt/herd			RM p= .000 CM p= .000	
Cultivate/hunt				RM p= .000 UM p= .000 CM p= .000 HD p= .003 HM p= .008 FM p= .013 FS p= .015

** = p<.005, * = p<.05
Tukey HSD test: TM = tibia midshaft, CM = clavicle midshaft
Tamhane test: RM = radius midshaft, UM = ulna midshaft, US = ulna sub-brachial, HD = humerus deltoid, HM = humerus midshaft, FM = femur midshaft, FS = femur sub-trochanter.

By continent (Table 3.47), the pattern is similarly complex. All indices differ significantly in the ANOVA, but post-hoc tests support this only between certain continents (Table 3.48). All indices differ significantly between Africa and Europe, Africa and the Americas, and Asia and the Americas. Europeans and Americans are more robust than Africans at all points. Asians are less robust than Americans at all points except the clavicle, which is significantly more robust.

Europe and the Americas are distinguishable only in terms of clavicular and tibial robusticity, where the tibia is more robust in Europeans, but the clavicle is less robust in Europeans. Africa and Asia are only significantly different in clavicular

robusticity, Asians having the more robust clavicle. Europe and Asia are significantly different in a sub-set of indices, representing the radius, tibia and femur, as well as the ulna midshaft robusticity index. At all these regions, Europeans are the more robust group.

Australasia shows no significant differences in comparison with Africa or Asia. Compared with Europe, both femoral indices are significantly more robust in Europeans. Compared to the Americas, Australasians are significantly more robust in the femur midshaft, but significantly less robust in the two humeral indices.

Table 3.47: Summary of diaphyseal robusticity by continent

	Africa			Europe			Americas			Asia			Australasia		
Variable	**Mean**	**S.D**	**N**	**Mean**	**S.D**	**N**	**Mean**	**S.D**	**N**	**Mean**	**S.D**	**N**	**Mean**	**S.D**	**N**
TMSRI	13.61	1.16	74	14.28	1.07	85	14.92	.99	138	13.60	1.16	42	14.10	1.17	19
RMSRI	11.27	1.18	73	12.22	1.05	84	12.02	1.32	136	11.00	1.21	42	11.44	1.36	18
UMSRI	11.51	1.29	75	12.43	1.23	83	12.43	1.20	137	11.45	1.55	43	11.76	1.31	19
USBRI	13.88	1.65	75	15.11	1.47	83	15.72	1.72	137	14.29	2.19	43	14.76	1.78	19
CMSRI	15.14	1.60	78	15.97	1.87	87	14.27	1.33	146	16.04	1.65	44	15.92	2.29	19
HMSRI	12.59	1.30	77	13.45	1.10	86	13.83	1.24	141	12.77	1.34	42	12.55	1.55	19
FMSRI	12.03	.81	77	12.70	.76	85	12.79	.85	143	11.74	.78	44	11.79	.84	19
FSTRI	12.22	1.03	77	13.50	.98	85	13.48	.85	143	11.86	.99	44	12.08	.89	19

Table 3.48: Summary of significant post-hoc tests by continent

Continent	Europe	Americas	Asia	Australasia
Africa	RM = .000 TM = .002 UM = .000 US = .000 CM = .027 HD = .004 HM = .000 FM = .000 FS = .000	RM = .000 TM = .000 UM = .000 US = .000 CM = .001 HD = .000 HM = .000 FM = .000 FS = .000	CM = .044	
Europe		TM = .000 CM = .000	RM = .000 TM = .020 UM = .005 FM = .000 FS = .000	FM = .002 FS = .000
Americas			RM = .000 TM = .000 UM = .003 US = .003 CM = .000 HD = .000 HM = .000 FM = .000 FS = .000	HD = .031 HM = .024 FM = .001

** = p<.005, * = p<.05 Tukey HSD test: RM = radius midshaft Tamhane test: TM = tibia midshaft, CM = clavicle midshaft, UM = ulna midshaft, US = ulna sub-brachial, HD = humerus deltoid, HM = humerus midshaft, FM = femur midshaft, FS = femur sub-trochanter.

Population profiles

The populations showing high femoral robusticity include the Inuit, Japanese, Poundbury, Prince Rupert Harbour and Sadlermiut groups (Figure 3.8). The South American, Lapp, Slavic and Arikara groups have high robusticity at the sub-trochanter location, but are not especially robust at midshaft. The Andaman, Kerma and Polynesian groups show low femoral robusticity.

For clavicle robusticity, the Terry, Lapp, Slavic and Andaman groups have high mean values, while the Hawikuh score low on this index (table 3.9). The Kerma and Polynesians score low on humeral robusticity, as for femoral robusticity, and the Japanese and Prince Rupert Harbour populations have the highest mean values. The patterns for radius, ulna and tibia robusticity, as well as humerus deltoid robusticity are very similar to those presented for the femur.

There are no clear links between the mean values exhibited by populations and their lifestyle categories. Agricultural populations do tend to rate high, with the exception of the Kerma, but hunt/fish populations are even more mixed. The links between climate and population are also ambiguous, as populations from cold climates are not exclusively high scoring on robusticity, and vice versa. Interactions between the five categories explored may be important, but the particular features of each of the populations are also relevant.

Table 3.8: Boxplot of femoral robusticity, by population

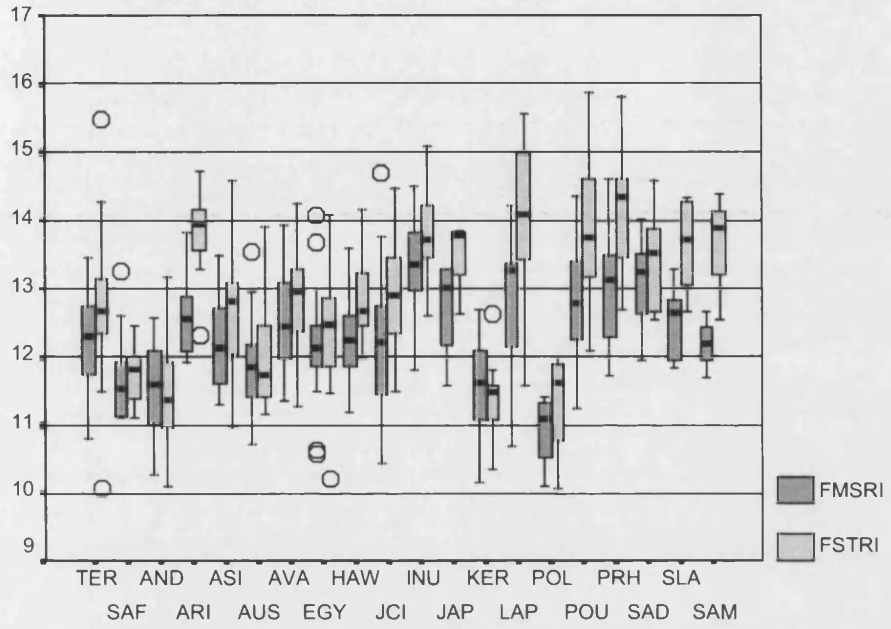
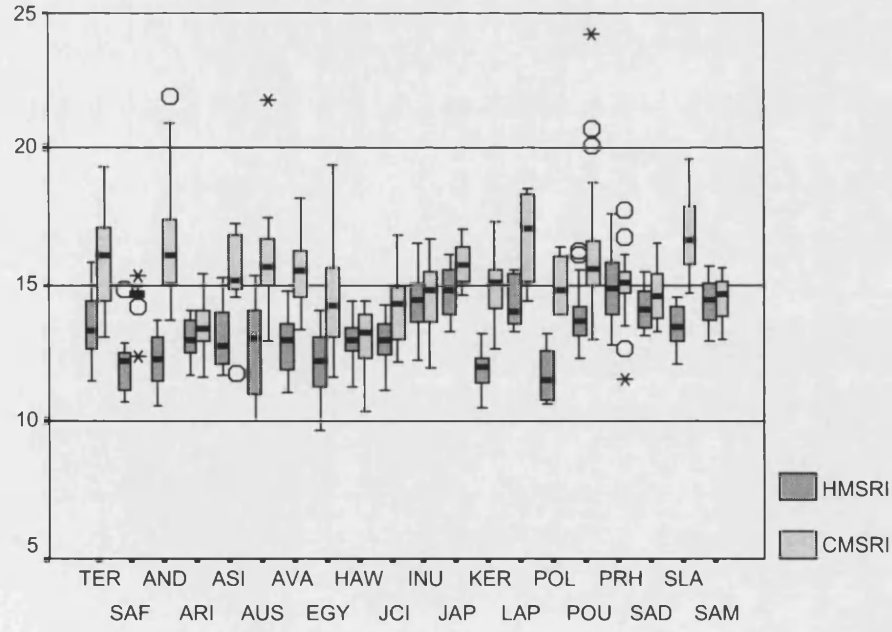


Table 3.9: Boxplot of clavicle and humeral robusticity, by population



Five-way ANOVA

When all other categories are held stable, only sex and lifestyle are significant influences on diaphyseal robusticity (Table 3.49). Sex is a significant influence on robusticity only for the clavicle and humerus midshafts. Lifestyle is a significant influence on robusticity at the radius, ulna, humerus midshafts and the femur sub-trochanter region, and significance is approached for the ulna sub-brachial robusticity index.

Despite the fact that males have been demonstrated to have longer and thicker bones than females in the analyses above, there is still a significant difference once indices of robusticity are calculated. Males have more robust limb bones for their length than females.

In the analyses for bone length and diaphyseal dimensions, lifestyle is only shown to be a significant influence for the humeral measurements, yet a significant lifestyle influence on robusticity is noted for locations on the radius, ulna, humerus and femur. The body size variability clearly obscures the assessment of significant differences between categories, even when using multi-way techniques. The use of indices, as a size -corrected measure, deals with this problem.

Table 3.49 : Summary of five-way ANOVA results, diaphyseal robusticity

	TMSRI					**RMSRI**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	212.013	252			none	209.636	251		
age	238.672	292	0.972	**ns**	age	249.834	291	1.028	**ns**
sex	280.463	286	1.166	**ns**	sex	265.724	285	1.116	**ns**
climate	234.079	266	1.046	**ns**	climate	242.071	266	1.090	**ns**
lifestyle	275.922	276	1.188	**ns**	lifestyle	287.863	275	1.253	**0.05**
continent	250.759	268	1.112	**ns**	continent	221.399	266	0.997	**ns**

	CMSRI					**UMSRI**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	532.785	266			none	213.269	255		
age	638.8	307	1.039	**ns**	age	268.412	296	1.084	**ns**
sex	768.42	300	1.279	**0.05**	sex	287.745	289	1.190	**ns**
climate	569.018	282	1.007	**ns**	climate	239.851	271	1.058	**ns**
lifestyle	605.014	292	1.034	**ns**	lifestyle	312.873	281	1.331	**0.05**
continent	614.508	283	1.084	**ns**	continent	231.121	272	1.016	**ns**

	USBRI					**HMSRI**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	416.603	255			none	219.863	260		
age	478.787	296	0.990	**ns**	age	263.346	301	1.035	**ns**
sex	543.572	289	1.151	**ns**	sex	346.802	294	1.395	**0.01**
climate	471.758	271	1.066	**ns**	climate	250.135	275	1.076	**ns**
lifestyle	564.942	281	1.231	**ns**	lifestyle	346.918	285	1.439	**0.01**
continent	481.517	272	1.084	**ns**	continent	253.946	276	1.088	**ns**

	FMSRI					**FSTRI**			
category excluded	SS	df	F		category excluded	SS	df	F	
none	112.015	262			none	150.553	262		
age	130.029	303	1.004	**ns**	age	178.412	303	1.025	**ns**
sex	155.642	296	1.230	**ns**	sex	185.125	296	1.088	**ns**
climate	116.278	278	0.978	**ns**	climate	170.661	278	1.068	**ns**
lifestyle	144.41	288	1.173	**ns**	lifestyle	219.281	288	1.325	**0.05**
continent	124.704	279	1.045	**ns**	continent	177.69	279	1.108	**ns**

Interactions between the categories are only significant in six cases (Table 3.50), all involving age, sex or both. Sex differences in clavicle robusticity are influenced by age, and age differences in ulna midshaft robusticity are influenced significantly by continent. Sexual dimorphism in humeral robusticity is influenced both by climate and lifestyle. The interaction between sex and lifestyle is also significant for the radial midshaft.

A three-way interaction between sex, age and lifestyle is significant for the humerus midshaft as well. This implies that age- and sex-specific humeral robusticity levels are influenced by the subsistence strategy in which an individual is involved. This is absolutely to be expected, but it is interesting that it is only significant for the humerus midshaft robusticity index.

Table 3.50: Summary of significant interactions between categories for diaphyseal robusticity

Significant interactions between two categories from four- and five-way ANOVA

Category excluded	age x sex	age x lifestyle	age x climate	age x continent	sex x lifestyle	sex x climate	sex x continent	lifestyle x climate	lifestyle x continent	climate x continent
None	CMSRI *			UMSRI *	RMSRI * HMSRI **		HMSRI *			

Significant interactions between three categories from four and five way ANOVA

	age x sex x lifestyle
None	HMSRI *

* = p < .05, ** = p < .01

Diaphyseal circularity indices

The diaphyseal circularity indices demonstrate the degree of anterior-posterior flattening at certain positions along the long bones. In the descriptive summary tables, mean figures over 1 indicate that the bone is thicker in the medio-lateral plane (cranio-caudal plane in the clavicle), while mean values under 1 indicate that the anterior-posterior plane is thicker. Most differences show only relatively more or less flattening, not a difference from the direction of flattening that is characteristic for that bone. Interpreting circularity indices is difficult, since a divergence from circularity may mean increased strain in one plane, or decreased strain in another. Furthermore, these patterns may be different for each bone, depending on its standard morphology.

Table 3.51: One-way ANOVA results on diaphyseal circularity

Circularity Index	Age		Sex		Climate		Lifestyle		Continent	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
TM	3.902	.009*	.925	.398	11.516	.000*	9.271	.000*	26.308	.000*
RM	1.529	.207	4.814	.009*	25.351	.000*	13.385	.000*	8.444	.000*
UM	10.729	.000*	4.257	.015*	6.883	.001*	5.152	.000*	6.893	.000*
US	.652	.582	2.858	.059	47.757	.000*	6.018	.000*	27.969	.000*
CM	1.361	.254	.135	.874	2.952	.053	4.914	.001*	6.688	.000*
HM	.944	.419	6.131	.002*	1.296	.275	6.260	.000*	8.562	.000*
FM	4.721	.003*	7.297	.001*	23.841	.000*	10.571	.000*	12.921	.000*
FS	2.271	.080	1.711	.182	22.011	.000*	9.080	.000*	6.734	.000*

* = p< .05

With increasing age, indices tend to move further from circularity for all bones (Table 3.53). Males and females show different patterns of circularity index across the body. At young and intermediate ages, females are more circular at the clavicle and femur

midshaft, but males are more circular at other points (Table 3.51). At older ages, females are more circular at the tibia, ulna and femur midshaft regions, while males are more circular.

The appropriate post-hoc tests fail to support any significant difference by age, although post-hoc tests do support the significant findings by sex (Table 3.52). In all four cases, the bones that differ significantly by sex have some surface feature that affects their circularity. The humerus has the attachment for the deltoid near the midshaft, the femur has the linea aspera, and the radius and ulna have rugged crests, formed by the interosseous membrane attachment. These surface features may also affect robusticity assessment, but they are notable here in that they may mask underlying flattening.

Table 3.52: Summary of significant post-hoc tests on diaphyseal circularity by sex

	Male
Female	RM p = .009 UM p = .014 HM p = .050 FM p = .001

Tukey test: UM: ulna midshaft, HM: humerus midshaft
Tamhane test: RM: radius midshaft, FM: femur midshaft

Table 3.53: Descriptive statistics for diaphyseal circularity by age and sex

Age Class	Circularity Index	Female			Male			Total (including unknown sex)		
		Mean	S.D	N	Mean	S.D.	N	Mean	S.D.	N
Under 30	**TMCI**	.85	.09	72	.86	.10	82	.86	.09	160
	RMCI	1.32	.12	74	1.29	.12	78	1.31	.12	158
	UMCI	1.25	.12	72	1.22	.12	81	1.23	.12	158
	USCI	.85	.10	72	.87	.11	81	.86	.11	158
	CMCI	.77	.08	75	.76	.07	82	.76	.07	163
	HMCI	.96	.09	74	.98	.08	82	.97	.08	162
	FMCI	.95	.07	73	.93	.09	82	.93	.08	161
	FSCI	1.27	.09	73	1.25	.12	82	1.26	.11	161
30 - 50	**TMCI**	.82	.08	59	.84	.09	68	.83	.09	137
	RMCI	1.35	.13	60	1.29	.11	69	1.32	.12	139
	UMCI	1.27	.11	61	1.22	.14	71	1.24	.13	141
	USCI	.84	.07	61	.86	.11	71	.85	.10	141
	CMCI	.78	.08	64	.77	.07	73	.78	.08	147
	HMCI	.96	.10	61	.98	.09	71	.97	.10	142
	FMCI	.97	.08	62	.93	.09	73	.95	.09	145
	FSCI	1.30	.14	62	1.27	.12	73	1.29	.14	145
Over 50	**TMCI**	.85	.08	20	.83	.10	23	.83	.10	44
	RMCI	1.35	.12	19	1.29	.11	23	1.31	.12	43
	UMCI	1.25	.11	22	1.18	.11	22	1.20	.13	45
	USCI	.87	.13	22	.83	.12	22	.85	.12	45
	CMCI	.78	.08	23	.79	.06	23	.78	.07	47
	HMCI	.92	.10	22	1.00	.12	23	.97	.13	46
	FMCI	.98	.07	23	.95	.08	23	.96	.08	47
	FSCI	1.29	.15	23	1.29	.12	23	1.29	.14	47

In the upper body regions where significant differences between sexes are found, males are more circular than females, but in the femur midshaft, females are more circular. This has specific implications for each bone, of course. In the radius and ulna, the bone is normally considerably thicker in the medio-lateral plane. Males and females both display this morphology, but it is less extreme in males. In the humerus, bones are slightly thicker in the anterior-posterior plane, but close to circular at the midshaft. However, males are significantly closer to circular, which may be due to hypertrophy around the deltoid attachment. In the femur, the situation

is reversed; all bones are slightly thicker in the anterior-posterior plane, but males are significantly less circular than females. This is likely to be due to hypertrophy at the linea aspera, surrounding the surface feature itself and affecting the cross-sectional measurement.

Table 3.54 : Descriptive statistics for diaphyseal circularity by climate

Circularity Index	hot			temperate			cold		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TMCI	.86	.09	146	.85	.09	145	.79	.08	67
RMCI	1.27	.11	144	1.32	.11	145	1.38	.13	64
UMCI	1.21	.13	148	1.25	.13	146	1.19	.16	63
USCI	.90	.10	148	.85	.10	146	.76	.08	63
CMCI	.77	.08	152	.76	.07	154	.79	.06	68
HMCI	.97	.10	149	.98	.09	150	.96	.13	66
FMCI	.92	.09	51	.98	.08	151	.92	.05	66
FSCI	1.25	.12	151	1.32	.11	151	1.23	.12	66

All circularity indices except those at clavicle and humerus midshaft are significantly different between climates, according to one-way ANOVA (Table 3.51). However, post-hoc tests support significance only between certain pairs of climatic categories. Between hot and temperate climates, the indices for the radius, ulna and femur show significant difference (Table 3.55). For all indices but the femur midshaft, those bones of hot climates are more circular. The femur midshaft is more circular in temperate climates. Between hot and cold climates only the tibia and radius midshafts and ulna sub-brachial region show significant difference. In all cases the hot climate bones are more circular.

The ulna sub-brachial region is the index which shows the most extreme differences between climatic categories (Table 3.54), where the medio-lateral plane is 90% of the anterior-posterior plane in hot climates, but only 70% of the anterior-posterior plane in cold climates. The temperate populations display an intermediate position. The underlying cause of this is likely to be hypertrophy below and around the insertion of *brachialis* in cold climate individuals, since most of the cold climate individuals come from populations known to be habitual sea rowers. Again, this identifies muscle attachment scars as perturbing influences on metric assessment of bones, beyond the boundaries of the insertion points themselves.

The comparison between temperate and cold climates produces most instances of significant difference. The clavicle is significantly more circular in cold than temperate climates (Table 3.55). The femur sub-trochanter index also follows this pattern, the rest of the significant results indicate greater circularity in the temperate climates than the cold climates.

Table 3.55: Summary of significant post-hoc tests by climate

Climate	Temperate	Cold
Hot	RM p= .000 UM p= .022 US p= .000 FM p= .000 FS p= .000	TM p= .000 RM p= .000 US p= .000
Temperate		TM p= .000 RM p= .005 UM p= .008 US p= .000 CM p= .023 FM p= .000 FS p= .000

HSD test: HM = humerus midshaft (Not significant), FM = femur midshaft
Tamhane test: TM = tibia midshaft, CM = clavicle midshaft, RM = radius midshaft, UM = ulna midshaft, US = ulna sub-brachial, FS = femur sub-trochanter.

By lifestyle, the pattern of significance is increasingly complex. All indices are significantly different, but post-hoc tests limit this significance to selected comparisons (Table 3.57). All lifestyle categories differ significantly in some way with all other categories. Hunt/fish and hunt/gather are very similar, differing significantly only in radius midshaft flattening, where the hunt/gather bone is more circular. Hunt/herd and agriculture strategies are also similar, differing significantly only in the femur sub-trochanter index. In this case, the bones of agricultural populations are more circular (Table 3.56).

Table 3.56: Descriptive statistics for diaphyseal circularity by lifestyle

Circularity Index	hunt/fish			hunt/gather			hunt/herd			cultivate/hunt			agriculture		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TMCI	.83	.10	110	.81	.08	34	.88	.09	46	.81	.08	80	.87	.08	88
RMCI	1.33	.12	108	1.24	.12	32	1.38	.12	45	1.26	.10	78	1.32	.10	90
UMCI	1.21	.14	110	1.16	.18	32	1.26	.15	46	1.21	.12	80	1.27	.11	89
USCI	.82	.12	110	.87	.10	32	.89	.09	46	.84	.10	80	.88	.10	89
CMCI	.79	.06	116	.77	.06	34	.75	.07	47	.78	.07	84	.75	.09	93
HMCI	.98	.11	113	.95	.10	34	.93	.07	46	1.01	.10	80	.96	.09	92
FMCI	.92	.07	114	.91	.09	33	1.00	.08	45	.94	.08	83	.96	.09	93
FSCI	1.25	.11	114	1.25	.11	33	1.31	.12	45	1.33	.12	83	1.25	.12	93

Hunt/gather skeletons differ from hunt/herd and agricultural skeletons in the same way, being significantly different at the tibia, radius and ulna midshaft. The tibia is less circular in the hunt/gather populations, but the radius and ulna are more circular than in either hunt/herd or agricultural groups. Between hunt/gather and cultivate/hunt groups, the same number of indices are significantly different, but in this case they are humerus midshaft, femur midshaft and femur sub-trochanter. Femur midshaft is less circular in hunt/gather skeletons, but femur sub-trochanter is

more circular in hunt/gather skeletons. Furthermore, typical flattening directions are opposite in these two regions, which means that cultivate/hunt femora show greater thickness in the anterior-posterior plane at midshaft, but hunt/gather femora show greater thickness in the medio-lateral plane at sub-trochanter. Humerus midshaft in the cultivate/hunt group is the only case where the typical direction of flattening is reversed. Here, the cross-section is close to circular, slightly thicker in the medio-lateral plane, whereas the hunt/gather group are less circular at humerus midshaft, and the flattening is in the perpendicular direction.

Table 3.57: Summary of significant post-hoc tests by lifestyle

Lifestyle	Hunt/gather	Hunt/herd	Cultivate/hunt	Agriculture
Hunt/fish	RM p= .003	TM p= .004 US p= .002 CM p= .013 HM p= .025 FM p= .000 FS p= .047	RM p= .000 FS p= .000	TM p= .004 UM p= .027 US p= .001 CM p= .001 FM p= .014
Hunt/gather		TM p= .003 RM p= .000 UM p= .017	HM p= .017 FM p= .000 FS p= .004	TM p= .005 RM p= .011 UM p= .002
Hunt/herd			TM p= .000 RM p= .000 US p= .050 HM p= .000	FS p= .029
Cultivate/hunt				TM p= .000 RM p= .000 UM p= .043 US p= .049 HM p= .005 FS p= .000

Tukey HSD test: UM = ulna midshaft, CM = clavicle midshaft, HM = humerus midshaft
Tamhane test: TM = tibia midshaft, RM = radius midshaft, US = ulna sub-brachial, FM = femur midshaft, FS = femur sub-trochanter.

The four lifestyle comparisons that reveal the most significant differences are between hunt/fish and hunt/herd, hunt/fish and agriculture, hunt/herd and cultivate hunt, and cultivate/hunt and agriculture (Table 3.57). All incorporate significant differences in the upper and lower body, or both proximal and distal elements. The clavicle is only of significance in the comparisons with the hunt/fish group. Cultivate/hunt and agriculture differ in six regions, and it is interesting to note that where other categories show significant differences with cultivate/hunt and agriculture, they are significant in non-overlapping subsets of those six regions.

Diaphyseal circularity indices show significant differences between continents, again restricted in post-hoc tests to particular comparisons (Tables 3.58 and 3.59). Asia and Africa differ only in the tibia midshaft, where the tibia is significantly more circular in Asian groups. Asia differs significantly from Europe in the femur and radius midshaft, being more circular in the radius, but less circular in the femur. There are no significant differences in diaphyseal circularity between the Asian and Australasian groups, nor between the African and Australasian groups. The Australasian category shows the least significant differences with any other category. It is significantly different from the European group in radius and femur midshaft, in the same pattern that distinguishes Europe from Asia. Ulna sub-brachial index is the only diaphyseal circularity index that significantly distinguishes Australasia from the Americas. Here the Australasian ulna is more circular.

Europe and the Americas are significantly different to all other continent categories, and are significantly different to each other in seven indices. Only femur sub-

trochanter index is not significantly different between these two continents. The European tibia midshaft, ulna sub-brachial, and femur midshaft indices indicate greater circularity, while the radius, ulna, clavicle and humerus midshaft regions are more circular in the Americas.

Table 3.58 : Descriptive statistics for diaphyseal circularity by continent

Circularity Index	Africa			Europe			Americas			Asia			Australasia		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TMCI	.83	.08	74	.89	.08	85	.79	.07	138	.91	.10	42	.85	.10	19
RMCI	1.27	.11	73	1.36	.10	84	1.31	.12	136	1.30	.11	42	1.24	.13	18
UMCI	1.21	.12	75	1.28	.13	83	1.19	.14	137	1.27	.09	43	1.18	.19	19
USCI	.90	.09	75	.88	.09	83	.79	.09	137	.92	.12	43	.85	.08	19
CMCI	.77	.08	78	.74	.07	87	.79	.06	146	.78	.08	44	.78	.05	19
HMCI	.93	.08	77	.95	.09	86	1.00	.12	141	.97	.07	42	.99	.11	19
FMCI	.93	.10	77	.99	.08	85	.94	.07	143	.91	.05	44	.90	.08	19
FSCI	1.23	.12	77	1.30	.11	85	1.30	.13	143	1.25	.09	44	1.24	.13	19

Table 3.59: Summary of significant post-hoc tests by continent

Continent	Europe	Americas	Asia	Australasia
Africa	TM p= .001 RM p= .000 UM p= .016 FM p= .000 FS p= .001	TM p= .007 US p= .000 HM p= .000 FS p= .000	TM p= .000	
Europe		TM p= .000 RM p= .004 UM p= .000 US p= .000 CM p= .000 HM p= .001 FM p= .000	RM p= .031 FM p= .000	RM p= .009 FM p= .001
Americas			TM p= .000 UM p= .008 US p= .000 FM p= .014	US p= .043

Tukey HSD test: UM = ulna midshaft, HM = humerus midshaft, FM = femur midshaft, FS = femur sub-trochanter. Tamhane test: TM = tibia midshaft, RM = radius midshaft, CM = clavicle midshaft, US = ulna sub-brachial, HD = humerus deltoid

Population profiles

The population profiles for diaphyseal circularity generally follow that for femur midshaft (Figure 3.10). The tibia circularity index produces a slightly different profile, so is presented here as well (Figure 3.11). Femur midshaft circularity is affected by the presence and size of the linea aspera or pilaster, whereby large pilasters tend to produce larger anterior-posterior diameters. Those populations where circularity of cross-section is approached are the Asian, Avar, Poundbury, Prince Rupert Harbour and Slavic groups. They are all temperate populations, and all European groups are included in this set. They can be considered to be relatively thicker than average in the anterior-posterior plane at this region. The few Polynesian individuals have the most extremely flattened femoral midshaft regions, relatively wider in the medio-lateral plane than is usual for this sample.

Figure 3.10: Boxplot of femur circularity index by population

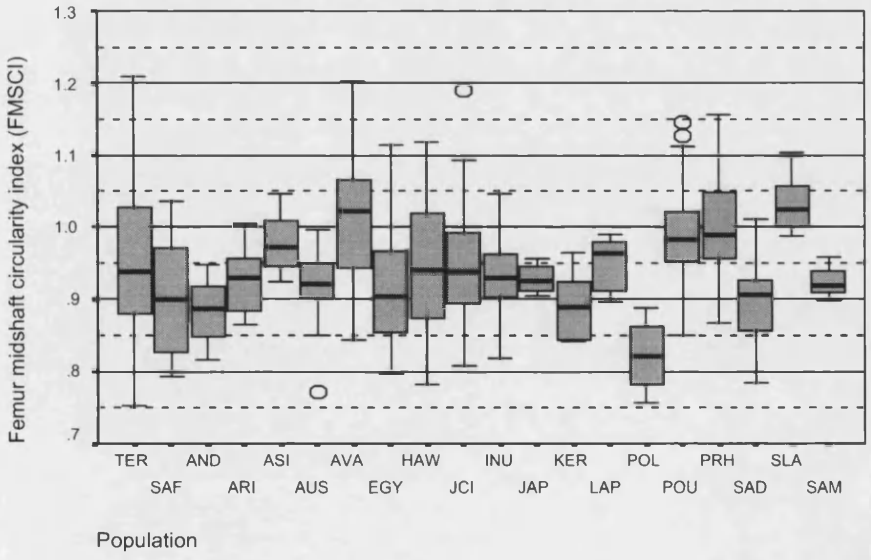
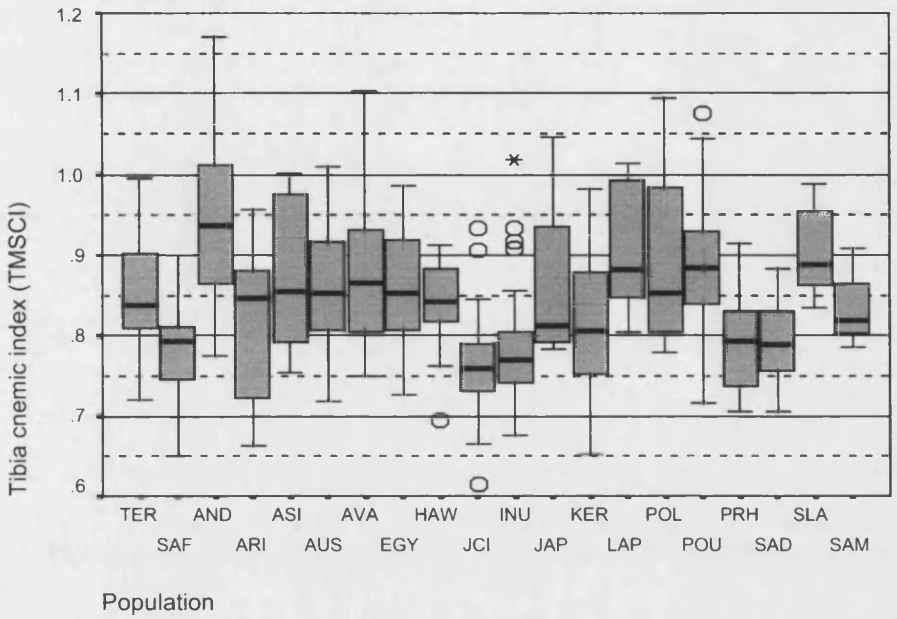


Figure 3.11 : Boxplot of tibia circularity index by population



The populations that come closest to circularity at the tibia midshaft are the Andaman Islanders (Figure 3.11). The populations with the most flattened tibiae include the Small African, Jersey County, Inuit, Prince Rupert Harbour and Sadlermiut groups. According to Lovejoy et al., (1976), this means that they are subject to most bending stress. This is the only time that the Small African and Andaman populations are found at opposite extremes of a variable, although there is some overlap at the tails of both distributions. Tibia cnemic or circularity index is associated with lower body strain, and the difference between Andaman and Small African populations in this index may relate to the mobility differences explored by Stock and Pfeiffer (2001). This can be summarised in that the Andamanese spend more time in boats fishing, and the Small African (Kalahari) people spend more time walking.

Five-way ANOVA

No category has a significant effect on diaphyseal circularity, when all other categories are held stable (Table 3.60).

Table 3.60: Summary of five-way ANOVA results, diaphyseal circularity

	TMSFI					**RMSCI**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	1.581	252			none	2.314	251		
age	1.806	292	0.986	**ns**	age	2.611	291	0.973	**ns**
sex	1.844	286	1.028	**ns**	sex	3.057	285	1.163	**ns**
climate	1.679	266	1.006	**ns**	climate	2.636	266	1.075	**ns**
lifestyle	1.759	278	1.009	**ns**	lifestyle	2.818	275	1.112	**ns**
continent	1.823	268	1.084	**ns**	continent	2.601	266	1.061	**ns**

	CMSCI					**UMSCI**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	1.427	266			none	3.382	255		
age	1.644	307	0.998	**ns**	age	3.744	296	0.954	**ns**
sex	1.592	300	0.989	**ns**	sex	4.125	289	1.076	**ns**
climate	1.51	282	0.998	**ns**	climate	3.508	271	0.976	**ns**
lifestyle	1.579	292	1.008	**ns**	lifestyle	4.119	281	1.105	**ns**
continent	1.537	283	1.012	**ns**	continent	3.911	272	1.084	**ns**

	USBCI					**HMSCI**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	1.752	255			none	1.476	260		
age	2.043	296	1.005	**ns**	age	1.791	301	1.048	**ns**
sex	2.121	289	1.068	**ns**	sex	1.867	294	1.119	**ns**
climate	1.848	271	0.993	**ns**	climate	2.094	275	1.341	**0.05**
lifestyle	2.008	281	1.040	**ns**	lifestyle	1.804	285	1.115	**ns**
continent	1.969	272	1.054	**ns**	continent	1.747	276	1.115	**ns**

	FMSCI					**FSTCI**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	1.489	262			none	2.866	262		
age	1.71	303	0.993	**ns**	age	3.267	303	.986	**ns**
sex	1.706	296	1.014	**ns**	sex	3.184	296	.983	**ns**
climate	1.661	278	1.051	**ns**	climate	3.417	278	1.124	**ns**
lifestyle	1.718	288	1.050	**ns**	lifestyle	3.335	288	1.059	**ns**
continent	1.597	279	1.007	**ns**	continent	3.093	279	1.013	**ns**

There are eight instances in which interaction between categories is significant (Table 3.61), all of which involve age, sex or both. Climate, lifestyle and continent do not themselves interact significantly, only with age or sex. The humerus is affected by a significant interaction between age and sex, and between a significant interaction between age, sex and lifestyle. The femur midshaft is affected by significant interaction between age and lifestyle, and the clavicle by significant interaction between age and climate. A significant interaction between sex and lifestyle is found for the radius, ulna midshaft and ulna sub-brachial regions. The tibia is affected by significant interaction between age and continent.

A significant interaction between two categories means that variation within one category is not random with respect to variation in the other category, for that variable. For diaphyseal circularity, this implies that for each of the bones, a sex- or age-based difference is mediated by another categorical variable. For example, tibia midshaft circularity varies with age, but the degree of age-related variation varies between continents, which may be a sign of genetic difference.

Table 3.61: Summary of significant interactions between categories for diaphyseal circularity

Significant interactions between two categories from four- and five-way ANOVA

Category excluded	age x sex	age x lifestyle	age x climate	age x continent	sex x lifestyle	sex x climate	sex x continent	lifestyle x climate	lifestyle x continent	climate x continent
None	HMSCI *	FMSCI *	CMSCI *		RMSCI ** UMSCI ** USBCI *		TMSCI *			

Significant interactions between three categories from four and five way ANOVA

	age x sex x lifestyle
None	HMSCI *

* = p < .05, ** = p < .01

Epiphyseal robusticity

Epiphyseal robusticity is used here to evaluate relative joint size, and thus provide information on the habitual weight bearing experiences of the joints. Despite being a size-corrected measure, males are significantly more robust than females across the body, and for all age classes (Tables 3.62 and 3.63). These differences are significant with post-hoc tests (Table 3.64)

Table 3.62: One-way ANOVA results for epiphyseal robusticity indices

	Age		Sex		Climate		Lifestyle		Continent	
Epiphyseal Robusticity Index	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**
TP	.841	.472	9.275	.000*	47.350	.000*	10.608	.000*	19.374	.000*
FP	2.546	.056	21.182	.000*	77.062	.000*	13.259	.000*	25.395	.000*
FD	.243	.866	42.247	.000*	17.251	.000*	2.795	.026*	6.068	.000*
HP	2.808	.040*	22.808	.000*	46.506	.000*	7.164	.000*	11.993	.000*
HD	.761	.517	14.161	.000*	4.938	.008*	1.419	.227	3.222	.013*
RP	5.452	.001*	5.964	.003*	64.776	.000*	9.148	.000*	11.993	.000*
UD	3.179	.025*	6.398	.002*	70.596	.000*	7.401	.000*	18.565	.000*

TP: Tibia proximal, FP: Femur proximal, FD: Femur distal, HP: Humerus proximal, HD: Humerus distal, RP: Radius proximal, UD: Ulna distal All are significant at the .05 level

Table 3.63: Descriptive statistics for epiphyseal robusticity by age and sex

Age Class	Female			Male			Total		
Epiphyseal Robusticity Index	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
Under 30									
TPJI	20.52	1.31	59	21.32	1.67	74	20.99	1.55	137
FPJI	9.98	.61	73	10.51	.79	81	10.25	.75	160
FDJI	16.14	.95	69	17.12	1.13	77	16.66	1.15	151
HPJI	13.72	.89	73	14.36	.94	82	14.05	.97	161
HDJI	18.52	1.49	73	19.59	1.54	82	19.11	1.59	160
RPJI	9.42	.67	74	9.73	.76	78	9.56	.74	158
UDJI	8.40	.87	42	8.78	.87	47	8.58	.88	92
30 - 50									
TPJI	20.78	1.26	52	21.46	1.59	58	21.16	1.48	120
FPJI	10.08	.61	62	10.62	.75	73	10.37	.73	145
FDJI	16.21	.93	62	17.29	1.01	70	16.77	1.09	140
HPJI	13.79	.74	61	14.69	.89	71	14.28	.93	142
HDJI	18.92	1.35	61	19.75	1.57	70	19.37	1.50	140
RPJI	9.76	.91	60	9.92	.82	69	9.84	.86	139
UDJI	8.67	.77	44	9.08	1.07	46	8.84	.95	95
Over 50									
TPJI	20.53	1.50	18	21.37	1.15	18	20.98	1.38	37
FPJI	10.25	.76	23	10.68	.56	23	10.46	.70	46
FDJI	16.24	.98	21	17.19	.88	23	16.74	1.03	44
HPJI	14.41	1.09	22	14.48	.79	23	14.45	.93	46
HDJI	19.31	1.13	22	19.27	1.19	23	19.29	1.15	45
RPJI	9.72	1.06	19	10.27	.90	23	10.01	.99	43
UDJI	9.18	.56	9	9.20	1.02	13	9.19	.84	22

Table 3.64: Summary of significant post-hoc tests on epiphyseal robusticity by sex

	Male
Female	TP p= .000 FP p= .000 FD p= .000 HP p= .000 HD p= .000 RP p= .007 UD p= .011

Tukey test: UD: Ulna distal, Tamhane test: All others

There are some significant increases in mean joint index with increasing age (Table 3.62). Although the humeral head index appears significantly different between ages, only the radial head and distal ulna indices are significantly different in post-hoc tests (Table 3.65). The radial head index is significantly lower in the youngest age class than both of the older age classes. The distal ulna index is significantly lower in the

youngest age class than the very oldest age class.

Table 3.65: Significant post-hoc test results for epiphyseal robusticity by age

Age Class	30-50	Over 50
Under 30	RP p= .013	RP p= .039 UD p= .026

RP: Radial proximal, UD: Ulna distal. Tamhane test used in all cases

By climate, significant differences are found in the majority of post-hoc tests (Table 3.67). All indices are significantly different between hot and temperate climates, with those in temperate climates being more robust. This pattern continues in comparisons between hot and cold, and temperate and cold climates. In all significant cases, the cooler climates are associated with higher levels of epiphyseal robusticity (Table 3.66).

Table 3.66 : Descriptive statistics for epiphyseal robusticity by climate

	hot			temperate			cold		
	Mean	**S.D.**	**N**	**Mean**	**S.D.**	**N**	**Mean**	**S.D.**	**N**
TP	20.28	1.27	139	21.43	1.36	115	22.20	1.39	51
FP	9.84	.60	151	10.54	.65	150	10.89	.66	62
FD	16.33	1.02	137	16.90	1.13	145	17.19	.96	58
HP	13.70	.85	149	14.43	.88	149	14.79	.77	66
HD	18.95	1.36	145	19.49	1.64	149	19.31	1.30	60
RP	9.30	.68	144	9.78	.64	145	10.53	.94	64
UD	8.21	.67	103	9.01	.78	63	9.66	.72	45

Table 3.67:Summary of significant post-hoc tests on epiphyseal robusticity by climate

Climate	Temperate	Cold
Hot	TP = .000 FP = .000 FD = .000 HP = .000 HD = .007 RP = .000 UD = .000	TP = .000 FP = .000 FD = .000 HP = .000 RP = .000 UD = .000
Temperate		TP = .004 FP = .002 HP = .010 RP = .000 UD = .000

** = p<.005, * = p<.05
Tukey HSD test: RM = radius midshaft
Tamhane test: TM = tibia midshaft, CM = clavicle midshaft, HM = humerus midshaft (Not significant), FM = femur midshaft, UM = ulna midshaft, US = ulna sub-brachial, FS = femur sub-trochanter.

The pattern of significant difference is more complex in comparisons by lifestyle (Table 3.69). One-way ANOVA indicates that all but the humerus distal index are significant (Table 3.62), but some pairs of lifestyle categories show many significant differences, while some show none. Agriculture shows only a few significant differences compared with all other lifestyle categories. Only the tibia proximal index is significantly different to that of the hunt/fish lifestyle, with agriculturalists having more robust tibiae (Table 3.68). The same is true for agriculturalists when compared with hunt/gather people, but the femur proximal index (femoral head) is significantly less robust in agriculturalists. The proximal femur is significantly less robust in agriculturalists than hunt/herders, and the proximal radius is significantly less robust in agriculturalists than in cultivate/hunt people (Table 3.68).

Hunt/fish and hunt/herd people show no significant differences in epiphyseal robusticity, and hunt/gather people show no significant differences to cultivate/hunt people. However, each member of these pairs of lifestyles is significantly different to

members of the other pair, in several indices (Table 3.69). This means that there are effectively three relevant lifestyle classes in determining influence on epiphyseal robusticity. Hunt/fish and hunt/herd people form one class, notably the most robust at all joints. Hunt/gather and cultivate/hunt people form a second class, while agriculturalists form the third class. Hunt/gather and cultivate/hunt people have the lowest epiphyseal robusticity, while the agriculturalists fall intermediate in all epiphyseal indices. The hunt/gather people have the smallest joint surfaces for their bone lengths in the whole sample. Hunt/gather and cultivate/hunt people may simply carry less mass for their height, either as body fat stores, or as muscle mass.

Table 3.68: Descriptive statistics for epiphyseal robusticity by lifestyle

	hunt/fish			hunt/gather			hunt/herd			cultivate/hunt			agriculture		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TP	21.62	1.48	88	19.93	1.53	32	21.55	1.76	31	20.71	1.17	75	20.94	1.41	79
FP	10.50	.81	110	9.73	.73	33	10.71	.78	45	10.08	.53	83	10.30	.66	92
FD	16.97	1.11	108	16.47	1.43	18	16.83	1.13	44	16.51	1.05	79	16.59	1.02	91
HP	14.45	.99	113	13.75	1.11	34	14.46	.81	46	13.91	.84	80	14.17	.88	91
HD	19.29	1.21	108	18.95	1.48	30	19.51	1.29	45	18.98	1.47	80	19.36	1.86	91
RP	9.90	1.00	108	9.37	.83	32	10.02	.98	45	9.34	.44	78	9.82	.66	90
UD	9.02	1.12	83	8.42	.69	15	9.90	.60	5	8.41	.63	71	8.83	.69	37

Table 3.69: Summary of significant post-hoc tests on epiphyseal robusticity, by lifestyle

Lifestyle	Hunt/gather	Hunt/herd	Cultivate/hunt	Agriculture
Hunt/fish	TP p= .000 FP p= .000 HP p= .016 RP p= .009		TP p= .000 FP p= .000 FD p= .042 HP p= .001 RP p= .000 UD p= .000	TP p= .023
Hunt/gather		TP p= .002 FP p= .000 HP p= .023 RP p= .004 UD p= .009		TP p= .022 FP p= .001
Hunt/herd			FP p= .000 HP p= .004 RP p= .000 UD p= .002	FP p= .011
Cultivate/hunt				RP p= .001

Tukey HSD test: FP: Femur proximal, HD: Humerus distal (not significant), RP: Radius proximal, UD: Ulna distal. Tamhane test: TP: Tibia proximal, FD: Femur distal, HP: Humerus proximal

Europe and Africa show the most significant differences in epiphyseal robusticity (Table 3.69). All seven indices are significantly different, with Europeans being more robust at all points. Europe shows no significant differences with the Americas, despite being very different in circularity index (Table 3.70). Three indices are significantly different between Europe and Asia, and six are significantly different between Europe and Australasia; in all cases European epiphyses are more robust.

The epiphyseal robusticity of the American sample differs from the African, Asian and Australasian samples in much the same ways as the European sample differs from them, although fewer comparisons produce significant differences. Europe and America have the largest joints for their bone length, while the other three continents have smaller joints for their bone length.

Table 3.70 : Descriptive statistics for epiphyseal robusticity by continent

Epiphyseal Robusticity Index	Africa			Europe			Americas			Asia			Australasia		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TP	20.02	1.26	71	21.35	1.41	61	21.60	1.33	115	21.26	1.48	40	19.87	1.51	18
FP	9.82	.64	77	10.63	.70	84	10.56	.66	139	9.99	.69	44	9.81	.67	19
FD	16.22	1.03	64	16.81	1.04	84	16.95	1.13	134	16.76	.88	39	16.25	1.31	19
HP	13.72	.83	77	14.44	.77	85	14.43	.95	141	14.09	1.02	42	13.57	.99	19
HD	18.94	1.60	73	19.61	1.90	85	19.21	1.21	136	19.39	1.02	41	18.57	1.36	19
RP	9.51	.70	73	9.97	.81	84	9.91	.83	136	9.15	.79	42	9.30	.80	18
UD	8.29	.72	42	9.49	.69	12	9.11	.85	110	8.07	.84	33	8.42	.48	14

Table 3.71: Significant post-hoc tests on epiphyseal robusticity, by continent

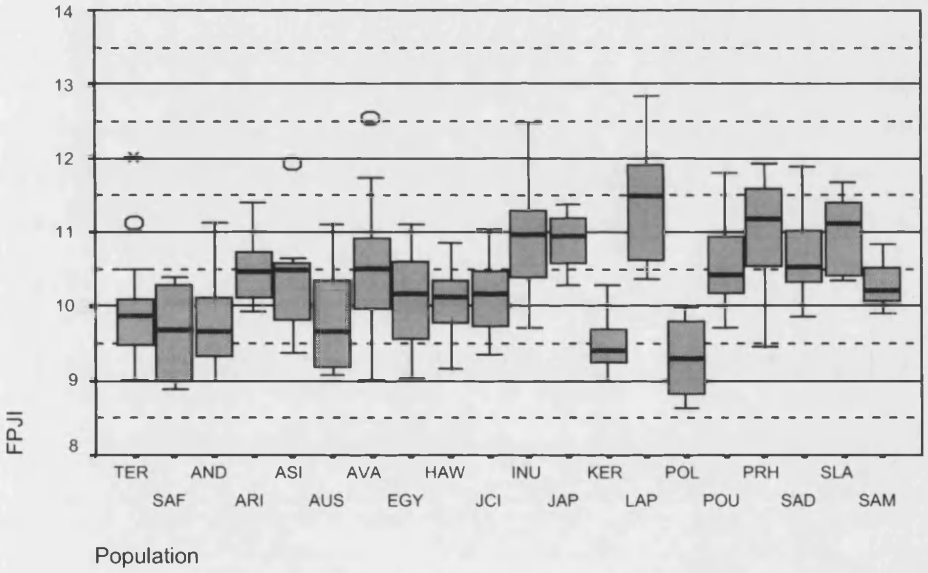
Continent	Europe	Americas	Asia	Australasia
Africa	TP p= .000 FP p= .000 FD p= .007 HP p= .000 HD p= .035 RP p= .002 UD p= .000	TP p= .000 FP p= .000 FD p= .000 HP p= .000 RP p= .003 UD p= .000	TP p= .000	
Europe			FP p= .000 RP p= .000 UD p= .000	TP p= .009 FP p= .001 HP p= .015 HD p= .041 RP p= .036 UD p= .002
Americas			FP p= .000 RP p= .000 UD p= .000	TP p= .001 FP p= .001 HP p= .015
Asia				TP p= .026

Tukey HSD test: HD: Humerus distal Tamhane test: All others

Population profiles

Those populations that score high on femoral head robusticity (FPJI) include the Inuit, Japanese, Lapp, Prince Rupert Harbour and Slavic groups (Figure 3.12). They have means above 10.9, compared with the 75th percentile for the whole data set of 10.78. The populations with low means are the Small African, Andaman, Australian, Kerma and Polynesian groups, which are all below the 25th percentile of 9.81.

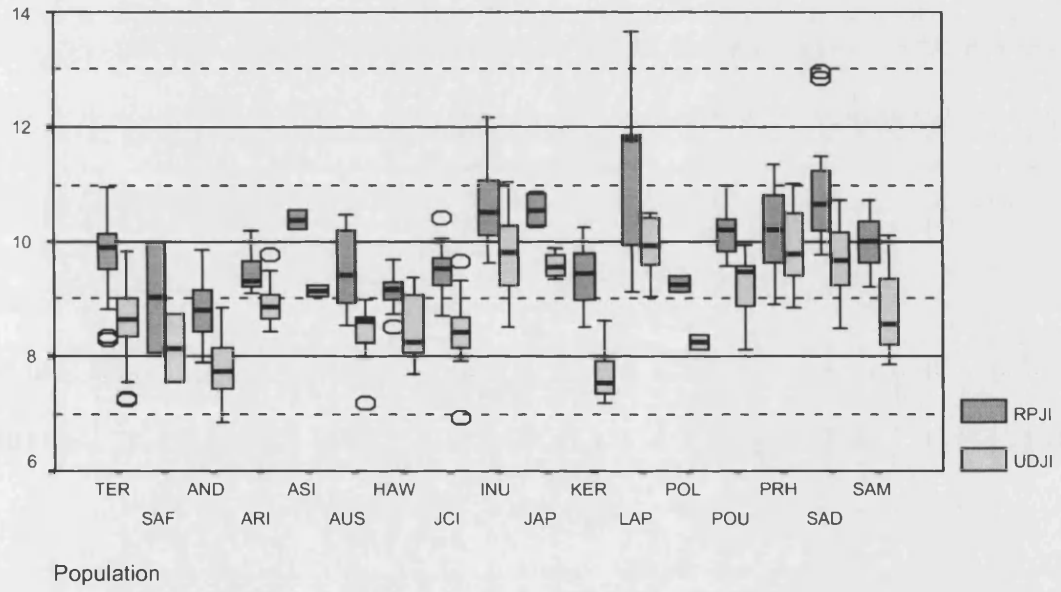
Figure 3.12: Boxplot of femur proximal joint index, by population



The other epiphyseal robusticity indices follow this pattern, with the exception of ulna distal joint index (UDJI) and radial head index (RPJI). Here the patterns are similar, but with slight variation. For the radial head index, the Arikara and Sadlermiut populations join the high scoring populations with mean indices around or over the 75th percentile of 10.22 (Figure 3.13). Only the Small African and Andaman groups can be considered low scoring on this index, with means under the 25th percentile of

9.18. The Hawikuh and Polynesian have means close to this value. For the ulna distal index, the Poundbury group is included with the other high scoring populations, with means over the 75th percentile of 9.46. At the other end of the scale, only the Small African and Andaman and Kerma groups can be considered low scoring on this index, with means under the 25th percentile of 8.13.

Figure 3.13: Boxplot of radial proximal joint index and ulna distal joint index, by population



The findings from the descriptive statistics translate into the population profiles in a straightforward manner. The Inuit, Sadlermiut, Prince Rupert Harbour and Lapp populations are all cold climate, hunt/fish or hunt/herd groups, from America or Europe. They show high scores on some of the robusticity indices depicted, while the low scoring groups include the Kerma, Polynesian, Australian and Small African groups, which are all hot climate groups from Australasia and Africa.

The low-scoring Andaman Islanders are hot climate, hunt/fish people, categorised as Asian for this purpose, and the high-robusticity Japanese are modern agricultural people, from a temperate climate in Asia. While the Asian means are generally intermediate, these two extremes of robusticity are present within the sample. The hunt/herd Slavic population show high robusticity for many indices, including the femoral head index. However, there are too few individuals for which indices can be calculated for indices including the radial and ulna indices.

Five-way ANOVA

Sex and lifestyle are the only categories that have a significant effect on epiphyseal robusticity, when other categories are held constant (Table 3.72). Sex is the only significant category for the distal femur (FDJI) and humerus head (HPJI), and approaches significance for the femoral head index (FPJI). Lifestyle is the only significant category for the distal ulna index (UDJI) and the tibia plateau index (TPJI).

The tibia plateau and distal ulna indices show significant differences with lifestyle and may therefore be responding to different kinds of activity. The five lifestyle categories must vary in the degree and kind of stress that they exert on the wrist and the knee joints, which is only apparent when the measurements are size-corrected. However, the proximal tibia is affected significantly by lifestyle, but the distal femur is not. The relevant forces are therefore likely to be associated with musculature inserting around the proximal tibia, including the tibial tuberosity, rather than with musculature inserting around the femoral condyles. The hunt/fish people have high mean

epiphyseal robusticity at the proximal tibia and distal ulna, and the hunt/herd group have high robusticity at the distal ulna. Strong wrist activity is likely to be a cause of increased distal ulna joint robusticity. This may involve twisting or other loading, from activities such as using reins or dragging large carcasses.

Table 3.72: Summary of five-way ANOVA results for epiphyseal robusticity

	TPJI					**FPJI**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	261.67	209			none	73.134	261		
age	298.496	247	0.965	**ns**	age	84.943	302	1.0038	**ns**
sex	338.492	241	1.122	**ns**	sex	101.661	295	1.2299	**ns**
climate	326.072	222	1.173	**ns**	climate	83.294	277	1.0731	**ns**
lifestyle	368.189	232	1.268	**0.05**	lifestyle	90.319	287	1.1231	**ns**
continent	317.394	225	1.127	**ns**	continent	80.263	278	1.0304	**ns**

	FDJI					**RPJI**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	200.177	253			none	91.828	251		
age	233.683	290	1.018	**ns**	age	123.971	291	1.164	**ns**
sex	305.605	285	1.355	**0.05**	sex	116.137	285	1.114	**ns**
climate	236.51	267	1.120	**ns**	climate	112.981	266	1.161	**ns**
lifestyle	233.257	274	1.076	**ns**	lifestyle	110.58	275	1.099	**ns**
continent	215.143	266	1.022	**ns**	continent	97.255	266	0.999	**ns**

	HPJI					**UDJI**			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	136.132	259			none	49.526	142		
age	165.589	300	1.050	**ns**	age	60.121	172	1.002	**ns**
sex	199.188	293	1.293	**0.05**	sex	63.202	168	1.079	**ns**
climate	150.048	274	1.042	**ns**	climate	52.039	152	0.982	**ns**
lifestyle	169.344	284	1.134	**ns**	lifestyle	76.479	156	1.406	**0.01**
continent	151.938	275	1.051	**ns**	continent	56.728	153	1.063	**ns**

The distal femur and humeral head indices are affected significantly by sex, although body size differences have been removed through the calculation of indices. Males remain more robust at these epiphyseal regions than females.

Interactions between categories are only significant for three joint indices, the two humeral indices (HDJI, HPJI) and the radial head index (RPJI). As in the previous analyses, all significant interactions involve age, sex or both categories (Table 3.73). The radial head index is affected by significant interactions between age and sex, age and climate, and age, sex and climate. The humeral head index is affected by significant interactions between age and sex, sex and lifestyle and sex and continent. The humerus distal index is affected by significant interactions between sex and lifestyle and sex and continent only. There are no significant interactions between climate, lifestyle and continent themselves.

Alongside age and sex differences, the radial head is influenced by climate, while the humerus is influenced by lifestyle and continent. None of the other joint indices, at the femur epiphyses or ulna distal joint, show any significant interactions. As assessments of weight bearing through body mass, upper body indices are not as useful as lower body indices. Variation in radial and humeral joint indices is more likely to relate to load bearing activities of the arm, or variation in the distribution of body mass between upper and lower bodies.

Table 3.73: Summary of significant interactions between categories for epiphyseal robusticity

Significant interactions between two categories from four- and five-way ANOVA

Category excluded	age x sex	age x lifestyle	age x climate	age x continent	sex x lifestyle	sex x climate	sex x continent	lifestyle x climate	lifestyle x continent	climate x continent
None	RPJI ** HDJI **		RPJI **		HPJI ** HDJI **		HPJI * HDJI **			

Significant interactions between three categories from four and five way ANOVA

	age x sex x climate
None	RPJI *

* = p < .05, ** = p < .01

The climatic effect noted on radial head index may be produced by the shortening of distal limb elements such as the radius in cold climates. There may also be climate-specific loading activities affecting the radius, but these would probably show up in a significant interaction between climate and lifestyle if relevant. The lifestyle effect on the humeral joints is likely to be driven by activity-related loading on the upper body, particularly since the humerus has previously been noted to be sensitive to lifestyle related variation in activity through robusticity. The effect of continent on sexual dimorphism in the humerus joint indices may be related to differences in subsistence activity, but an ethnic or genetic effect cannot be ruled out.

Principal Components Analyses

The basic metric variables used to construct the indices above were analysed using Principal Components data reduction techniques, utilising Varimax rotation (SPSS, 1999). Only 184 individuals possessed all variables, and the rest were eliminated from this analysis. Three components were extracted (Eigenvalues over 1), which together explain over 78% of the variance in the sample (Table 3.74). Although many variables load strongly on more than one component, the variables that load strongly on single components break down into distinct categories. The first component features lower body diaphysis cross-sections and epiphysis measurements. Particularly strong on this component are femur head diameter, femur medio-lateral diameters at midshaft and sub-trochanter, femur lateral condyle length and tibia plateau anterior-posterior length. These variables are likely to be associated with body size, since these are weight-bearing components of the skeleton.

The second component features upper body diaphyseal cross-sections and epiphyseal measurements. The variables that are strongly represented only on this component are clavicle midshaft diameters and ulna medio-lateral diameters at midshaft and sub-brachial points. All variables associated with the humerus and radius, plus other measurements from the tibia, femur and ulna are split between components 1 and 2. On component 3, the functional lengths of the radius, tibia and ulna are most strongly loaded, followed by the functional lengths of the humerus, clavicle and femur. These latter three variables load less strongly on component 1.

Table 3.74: Postcranial metric PCA: Rotated component matrix

(Including typical loading pattern and variance explained: sorted by size)

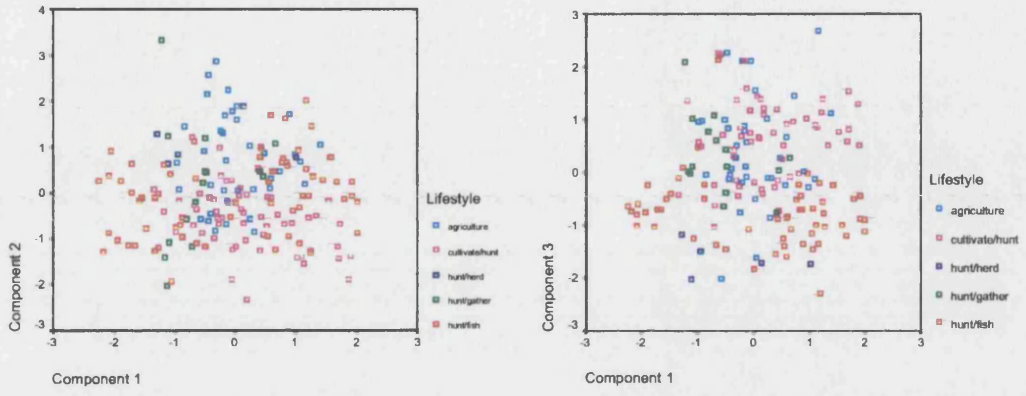
Component	1	2	3
FHDIA	.820	.397	.197
FMSML	.795	.326	.265
FLCL	.786	.270	.406
FSTML	.752	.289	.227
FMSAP	.737	.342	.250
FSTAP	.725	.442	.204
FDAB	.708	.403	.337
USBAP	.686	.558	.043
HDAB	.681	.553	.281
HTHB	.679	.535	.351
HTHD	.655	.435	.438
HMSAP	.645	.612	.226
HDEML	.632	.622	.114
TMSAP	.615	.218	.438
HTAB	.615	.512	.382
UMSAP	.615	.518	.352
RDATB	.611	.575	.245
CLMXL	.610	.295	.581
UDAMX	.601	.459	.386
UMSML	.433	.746	.283
CMSMX	.220	.736	.415
CMSMN	.341	.723	.299
USBML	.316	.719	.364
RHDIA	.399	.718	.324
RMSML	.544	.703	.031
HMSML	.594	.657	.139
HDEAP	.621	.655	.222
RMSAP	.472	.648	.449
RTL	.216	.642	.478
RTB	.305	.624	.140
RHDIA	.542	.543	.492
RFXL	.105	.224	.932
UFXL	.156	.245	.925
TFXL	.215	.184	.895
HFXL	.463	.286	.775
FFXL	.538	.211	.687
TMSML	.415	.428	.505
Typical variables loading	Lower body diaphysis and epiphysis measurements,	Upper body diaphysis and epiphysis measurements	Long bone lengths
Rotation Sums of Squared Loadings			
Total	10.463	9.241	6.163
% Variance	31.707	28.003	18.675
Cumulative %	31.707	59.710	78.385

All three components clearly relate in part to body size, but represent different aspects of body size. Component 1 represents body mass, and incorporates stature and torso width through the femur, humerus and clavicle lengths. Component 2 represents upper body bone thickness and perhaps comes closest to representing robusticity. Component 3 represents limb length, particularly distal limb length, and thus body proportions. Those variables that are not useful in distinguishing between these different aspects of body size load over multiple components. The fact that the medio-lateral diameters of the ulna and femur are more diagnostic than the anterior-posterior diameters of the same bones is interesting. These are the dimensions less affected by muscle markings, and perhaps more representative of the bone's 'true' thickness.

By lifestyle, component 1 splits the hunt/fish category into opposite extremes (Figure 3.14). This body size component is detecting the difference between the stocky Canadian hunt/fish people (Prince Rupert Harbour, Inuit and Sadlermiut) versus the delicately built tropical hunt/fish people (Andamanese). Component 1 also places the cultivate/hunt group high, while the other categories remain intermediate. Component 2 pulls the agricultural and cultivate/hunt categories slightly apart, which corresponds to the finding that these two groups differ most in upper body robusticity. Component 3 produces reasonable separation between the shorter hunt/fish and hunt/herd group and the taller cultivate/hunt group.

Figures 3.14 a :Postcranial metric PCA components 1 and 2, by lifestyle and

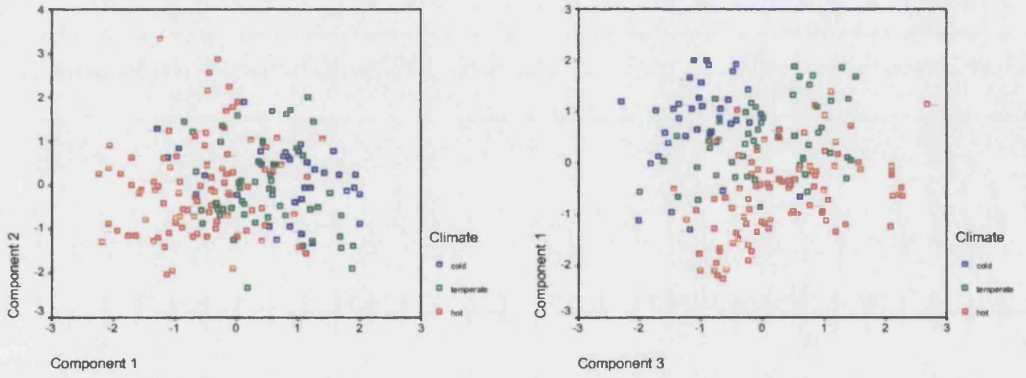
b. Postcranial metric PCA components 3 and 4, by lifestyle



a. b.

Figure 3.15 a. Postcranial metric PCA components 1 and 2 by climate

b. Postcranial metric PCA components 3 and 4 by climate

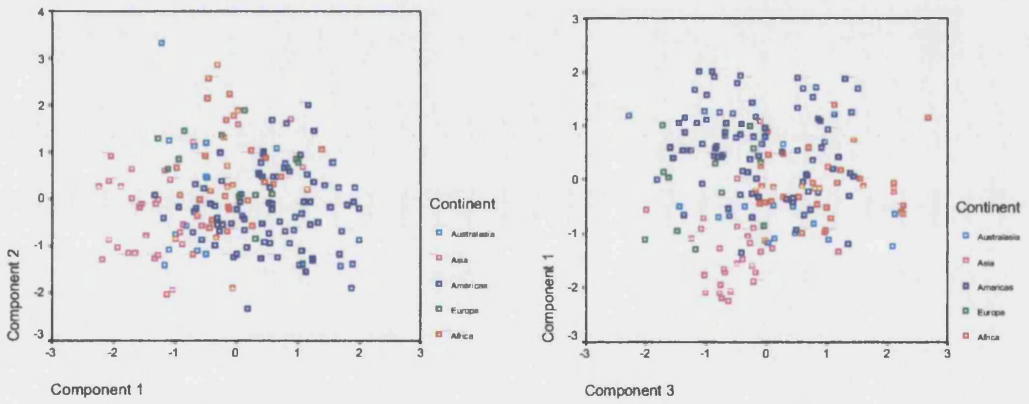


a. b.

Separation by climate is more clear cut, and the hot and cold populations disperse to opposite extremes on component 1 (Figures 3.15 a and b). Temperate populations remains intermediate, and neither components 2 nor 3 produce separation between the climatic groupings.

Separation by continent is also informative, producing good separation between the Asians and Americans on component 1, the size-based component. Component 2 has separation effect, but component 3 separates the Europeans from the Africans (Figures 3.16 a and b). Since this is the distal long bone length component, this is detecting the classic difference in body form between African and European populations, supporting Holliday (1995) and others. The lack of a separation effect using the climatic categorisation stems from the inclusion of the short statured Andamanese in the hot climate category. Their short limbs bring their scores on Component 3 down considerably lower than the rest of the hot climate people (Figure 3.16 b).

Figure 3.16 a Postcranial PCA components 1 and 2 by continent b. Postcranial PCA components 1 and 3 by continent

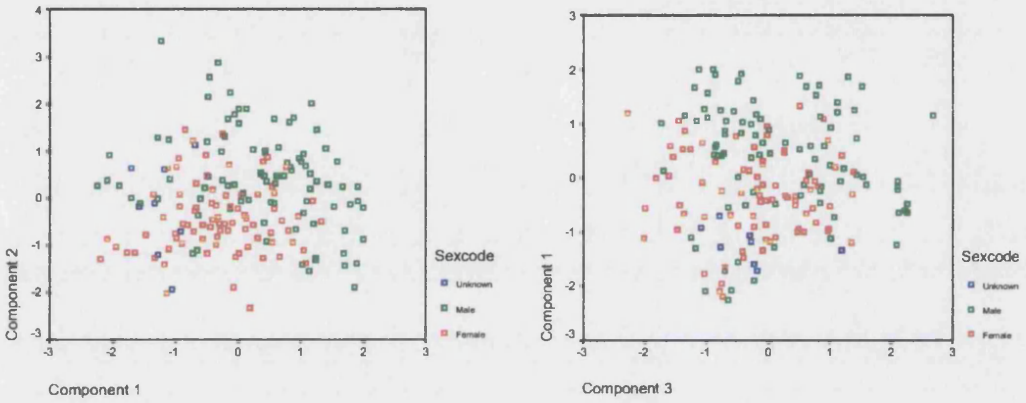


a.

b.

No separation effects are seen by age on any of the components, but some separation is seen by sex (Figures 3.17 a and b). Males tend to be placed higher on all components, although there is a great deal of overlap.

Figure 3.17 a Postcranial PCA components 1 and 2 by sex b. Postcranial PCA components 3 and 4 by sex



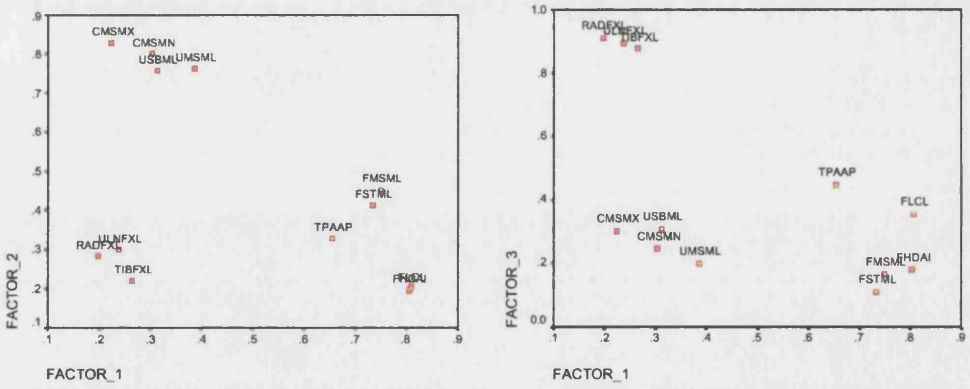
To establish whether the patterns detected in the first PCA are likely to apply to the whole data set, the analysis was repeated using fewer variables, in order to maximise sample size. For example, the hunt/herd category is under-represented in the first PCA, due to missing variables. The twelve most diagnostic variables, listed above, were used, and produced three components. These components were loaded as before, but components 2 and 3 were reversed in the percentage of variance explained (Table 3.75). Using this larger sample size of 289 individuals, the patterns in graphs by category produced the same pattern. Where small numbers or even individual members of a population appeared in the graphs above, they were shown be typical of their populations.

Table 3.75: Postcranial metric PCA 2: Rotated component matrix

(Typical loading pattern and variance explained: sorted by size)

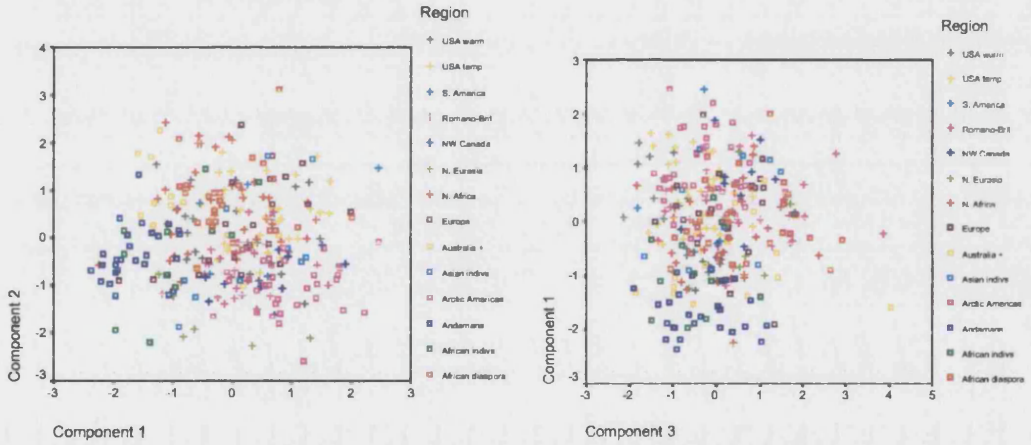
Component	1	2	3
FLCL	.808	.202	.354
FHDAI	.804	.195	.179
FMSML	.749	.452	.165
FSTML	.733	.412	.109
TPAAP	.655	.329	.448
CMSMX	.224	.828	.301
CMSMN	.304	.801	.245
UMSML	.386	.762	.200
USBML	.313	.757	.307
RADFXL	.197	.283	.911
ULNFXL	.239	.298	.895
TIBFXL	.265	.220	.876
Typical loaded variables	Lower body diaphysis and epiphysis measurements	Long bone lengths	Upper body diaphysis and epiphysis measurements
Rotation Sums of Squared Loadings			
Total	3.651	3.124	3.111
% Variance	30.426	26.037	25.925
Cumulative %	30.426	56.464	82.389

Figure 3.18 : Postcranial PCA 2 a. components 1 and 2 by variable and b. components 1 and 3 by variable



The plots above show the component scores for each of the twelve variables, indicating the grouping of variables in three clusters (Figures 3.18 a and b). For added clarity, the bivariate plots below show the component scores marked by region rather than population (Figures 3.19 a and b) . This simplifies the graph by marking the Inuit and Sadlermiut together as Arctic Americas, the Kerma and Egyptian together as North Africa, the Avar and Slavic populations together as Europe, and the Illinois and Arikara together as temperate USA.

Figure 3.19 : Postcranial PCA 2 a. components 1 and 2 by population and b. components 3 and 4 by population



The principal components analysis distinguishes certain populations very well. In general, those individuals that are high on Component 1 (in both analyses) tend to be males, some of the hunt/fish people, most cultivate/hunt people, people from cold and some temperate climates, and many from the American continent. The main populations that score high on this general body mass component are the Inuit, Sadlermiut, (Arctic Americas) and Prince Rupert Harbour. Individuals from Siberia,

the Terry Collection of US Blacks, Poundbury and Japan also tend towards high positions on component 1. Those groups that are low on component 1 are some of the hunt/fish people, Asians, and people from hot climates. The small Andamanese are the main population in this position, accompanied by individuals from the San group and the Hawikuh.

Component 2 (or Component 3 in analysis 2), representing upper body bone thickness, produces separation only in sex and lifestyle. Males tend to be higher than females, and hunt/herd and agricultural groups also tend to score high. The populations that score high on this component include the Slavic, Terry and Poundbury populations, all hunt/herd or agricultural individuals. The Hawikuh and Arikara, who are classified as cultivate/hunt populations, score low.

Groups high on component 3, representing long bone length, especially distal limb length, include agriculturalists, cultivate/hunt and hunt/gather groups. They also tend to be from hot or temperate climates, and include some Americans, and most Africans. The populations in this category are the Terry, Kerma and Arikara, plus some Australian individuals. Populations low on component 3 tend to be from hunt/fish populations or from Europe or Asia or parts of the Americas. These populations are typically the Inuit, Sadlermiut, Lapp, Prince Rupert Harbour and Andamanese.

Chapter Summary

The most important influences on postcranial metric data are sex and lifestyle, which permeate the data set, even once size-corrected indices of robusticity have been produced (Table 3.76). Climate and continent only produce significant differences for certain bone lengths, which are generally lost once indices are produced. The exception is for humerus circularity index, which retains a significant climatic influence. Age has no significant effect on any variables, except in terms of interaction effects with other categories.

Diaphyseal robusticity is only affected significantly by sex and lifestyle, once other categories are held constant. The areas that are affected are predominantly in the upper body, which can be seen as being more sensitive to robusticity variation than the lower body. The exception is the femur sub-trochanter region, where robusticity variation appears to be more responsive than the midshaft region. Since there is no reason to suppose that different long bones respond differently to the same levels of stress, it is more parsimonious to suggest that the levels of stress are more variable in the upper body than they are in the lower body. The lower limbs are subjected to less variation in activities than the upper limbs and shoulder girdle, and thus do not exhibit significant differences by lifestyle or other categories.

Table 3.76: Summary of significant results for postcranial metric data

Variable type	Significant results
Bone length	Sex affects all bone lengths Climate affects tibia, radius and ulna lengths Lifestyle affects ulna and humerus lengths Continent affects ulna lengths
Diaphyseal diameters	Sex affects all diameters Lifestyle affects both humerus midshaft diameters
Epiphyseal dimensions	Sex affects all dimensions Lifestyle affects both humerus epiphyseal dimensions
Body shape	No effect from any category
Diaphyseal robusticity	Sex affects clavicle and humerus robusticity Lifestyle affects radius, humerus, ulna midshaft and femur sub-trochanter robusticity
Diaphyseal circularity	Climate affects humerus circularity
Epiphyseal robusticity	Sex affects distal femur and proximal humerus joint robusticity Lifestyle affects proximal tibia and distal ulna robusticity

The populations used to represent categories in an analysis can strongly influence the results. Not all possible categories and permutations of categories are included in the data set. This is partly due to lack of appropriate population samples, but also due to true eco-geographical limitations, such as the climatic parameters that determine the viability of lifestyle strategies. Furthermore, it is not clear whether a hunt/gather strategy performed in hot climates is truly equivalent to the same

strategy performed in cold climates. Or indeed, whether the different technological heritage of each continent affects the success of different subsistence strategies.

Specific suites of traits for each population drive the way the variables are seen by category, and in essence, all lifestyle, climate and continent categories do, is split up the populations into different sets. While the matrix of possible permutations in these categories remains incomplete, then theoretically these three categories cannot be considered independent. However, significant interactions between these categories have not been consistently noted without the removal of other categories first, which implies that in this data set, lifestyle, climate and continent are acting independently of one another.

The principal components analyses identify three main vectors of variation, corresponding to lower body bone thickness, upper body bone thickness and general bone length. The ordering of these components depends on the sample and the variables used, but loading of variables on these components remain stable. The variables that will be carried into the discriminant function analysis comprise the eight variables that load most strongly on the principal components axes, and best distinguish the postcranial data. They are femoral head diameter, femur midshaft medio-lateral diameter, femur sub-trochanter medio-lateral diameter, clavicle midshaft maximum diameter, ulna midshaft medio-lateral diameter, ulna sub-brachial medio-lateral diameter, radius functional length, and tibia functional length.

Chapter 4 : Postcranial Scored Results

The postcranial scores are analysed through one-way and multi-way analysis of variance differences between age, sex, climate, lifestyle and continent categories. Population profiles for rugosity by each category are produced, using aggregated z-scores for functional regions of the body. Finally, eight variables are selected for use in discriminant function analysis, on the basis of their distinctiveness and ability to discriminate between populations.

The postcranial scores are not exclusively normally distributed, so one-way ANOVA is avoided, since there is a good alternative available. This is the Kruskal-Wallis test, which is useful in this situation, as it allows the use of ordinal data. It also provides a method of direct comparison between subgroups of the sample, in the manner of the post-hoc tests on the one-way ANOVAs in previous analyses. As with ANOVA, the test is to establish whether two or more subgroups can be considered to belong to the same population. There is no non-parametric alternative to multi-way ANOVA, however, so these techniques are used, but with conservative interpretation. Multi-way ANOVA is resistant to skew and kurtosis, and remains the most valid approach.

All scores are treated in the same way, but are discussed bearing in mind that they do not all refer to the same types of MSM. Some derive from syndesmoses, others are fibrous or fibrocartilaginous muscle attachments, and as such reflect different processes operating on bone (discussed above). Line graphs are produced to

summarise trends in rugosity patterning, but because the scores cannot be considered to be calibrated relative to each other, these graphs should be regarded simply as illustration of typical rugosity patterns for each sub-category in the data set.

Age

Several postcranial scores show significant difference between age classes and between the whole sample (Table 4.2). The mean score for the tibial tuberosity and the tibial soleal line (TTSCO and TSSCO) increases significantly from young to middle age, but then drops into older age, such that young and old adult scores are not significantly different (Table 4.1).

Table 4.1: Descriptive statistics for mean rugosity scores by age

	Under 30			30 - 50			Over 50		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TTSCO	2.61	.96	155	2.95	.87	136	2.83	.85	41
TSSCO	2.48	.80	159	2.77	.88	138	2.60	.71	43
FGSCO	2.92	.98	159	3.48	.92	144	3.62	.83	45
FPSCO	2.49	.82	159	2.89	.78	144	2.83	.75	46
USSCO	2.26	.76	159	2.34	.82	140	2.62	.94	45
UPSCO	2.86	.83	152	2.87	.93	138	3.38	1.05	42
UBSCO	2.79	.70	159	2.96	.72	140	2.96	.67	45
CWSCO	1.93	.74	147	2.29	.83	126	2.60	.69	41
CSSCO	2.58	.93	151	2.85	.95	130	2.65	1.00	42
CDSCO	2.76	.72	153	2.91	.74	134	2.96	.97	42
RTSCO	2.63	.77	158	2.87	.86	137	2.90	.90	42
RHSCO	1.90	.71	148	2.04	.82	132	2.14	.89	37
HDSCO	2.46	1.05	160	2.81	1.02	141	2.85	1.04	46
HISCO	2.59	.80	158	2.98	.84	139	3.14	.75	44

Ulna brachialis score is not significantly different between any age classes, but the supinator score is significantly different between the young and old age classes only. The ulna pronator score is significantly different between the oldest age class and each of the other age classes . In all positions on the ulna, the mean score increases with age.

On the clavicle, the score for wear at the sternal margins (CLSCO) is significantly different at all age class comparisons. The mean score increases into middle age and then falls into old age. The scores for the ligament attachments at the sternal end of the clavicle (CSSCO) are significantly larger in middle age than in the youngest age class, but no other comparisons are significant. At the distal ends, age makes no significant difference to the mean score (CDSCO).

The score for radial tuberosity score (RTSCO) only shows a significant difference between the means for the youngest and middle age classes, increasing throughout life (Table 4.2). The score for arthritic wear at the radial head (RHSCO) shows no significant difference with age, although the mean score increases with age.

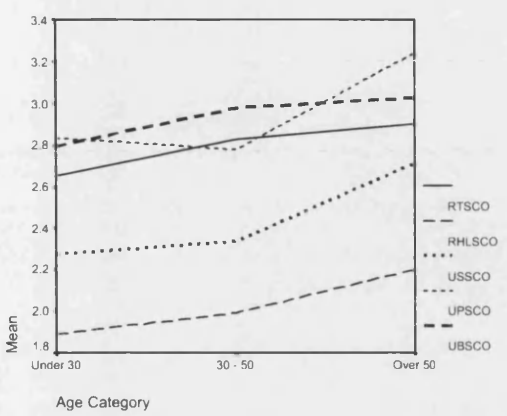
The scores for humerus deltoid and intertubercular groove (HDSCO and HISCO) behave similarly with respect to age. Both show significant differences between the youngest age class and each of the two older age classes and the mean score increases with age. The femur shows the same pattern on both the gluteal score and the pilaster score.

Summary

As expected, rugosity scores tend to increase with age, but the periods of life where this is detectable as significant vary between scores. Most show significant increases between attainment of adulthood and middle age, with no further increase after this. The scores on the tibia, femur, humerus, radial tuberosity and sternal clavicle follow this pattern. Two of the ulna scores, supinator and pronator, develop significant increases only in later life. Two further scores, ulna brachialis and distal clavicle, show no age effect on mean score (Figure 4.1).

Figure 4.1: Summary of age differences in rugosity patterning

a. ulna and radius, b. humerus and clavicle, c. tibia and femur



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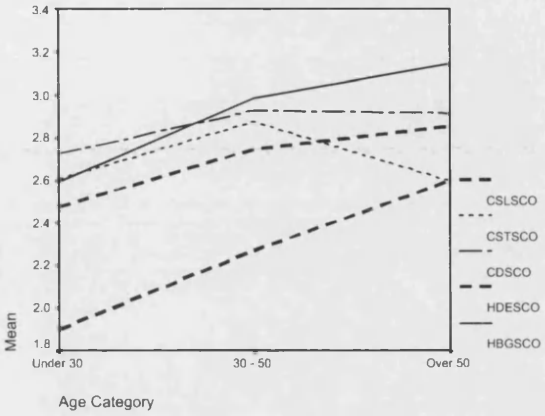

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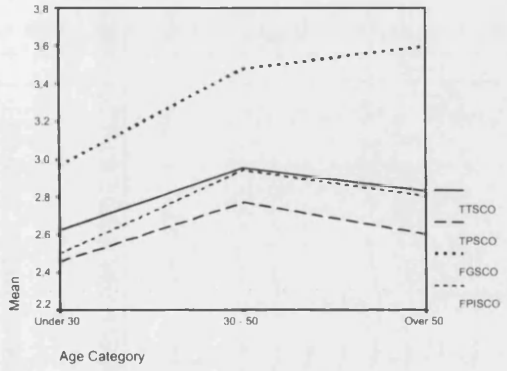


c

Score Legend

USSCO	Ulna supinator
UPSCO	Ulna pronator
UBSCO	Ulna brachialis
RTSCO	Radial tuberosity
RHLSCO	Radial head lipping
CSLSCO	Clavicle sternal lipping
CSSCO	Clavicle sternal ligament
CDSCO	Clavicle distal ligament
TTSCO	Tibial tuberosity
TPSCO	Tibia soleal line
FGSCO	Femur gluteal
FPSCO	Femur linea aspera
HDESCO	Humerus deltoid
HBGSCO	Humerus bicuspid groove

Table 4.2: Kruskal-Wallis test of age differences in postcranial scores

	TTSCO	TPSCO	USSCO	UPSCO	UBSCO	CSLSCO	CSTSCO	CDSCO	RTSCO	RHLSCO	HDESCO	HBGSCO	FGSCO	FPISCO
Under 30/30-50														
Chi-Square	10.556	7.359	.708	.003	3.175	13.742	5.571	2.942	5.828	2.014	7.084	17.138	24.915	20.155
df	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.001*	.007*	.400	.957	.075	.000*	.018*	.086	.016*	.156	.008*	.000*	.000*	.000*
30-50/Over 50														
Chi-Square	.770	1.080	3.569	7.964	.001	5.316	1.588	.126	.021	.202	.016	1.157	.575	.141
df	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.380	.299	.059	.005*	.972	.021*	.208	.723	.886	.653	.899	.282	.448	.707
Under 30/Over 50														
Chi-Square	1.981	.837	6.059	9.256	1.541	24.250	.115	.503	2.941	1.781	3.986	15.700	19.533	7.371
df	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.159	.360	.014*	.002*	.215	.000*	.735	.478	.086	.182	.046*	.000*	.000*	.007*
All sample														
Chi-Square	10.854	7.511	6.132	9.736	3.672	29.186	5.766	2.922	6.851	2.923	8.530	24.878	33.450	21.891
df	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.004*	.023*	.047*	.008*	.159	.000*	.056	.232	.033*	.232	.014*	.000*	.000*	.000*

* = p< .05

Table 4.3: Kruskal-Wallis test of sex differences in postcranial scores

	TTSCO	TPSCO	USSCO	UPSCO	UBSCO	CSLSCO	CSTSCO	CDSCO	RTSCO	RHLSCO	HDESCO	HBGSCO	FGSCO	FPISCO
Male/Female														
Chi-Square	23.658	2.613	9.260	.053	14.081	6.187	24.898	5.789	4.479	.409	7.846	11.469	.314	24.013
df	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.000*	.106	.002*	.818	.000*	.013*	.000*	.016*	.034*	.523	.005*	.001*	.575	.000*

* = p< .05

Sex

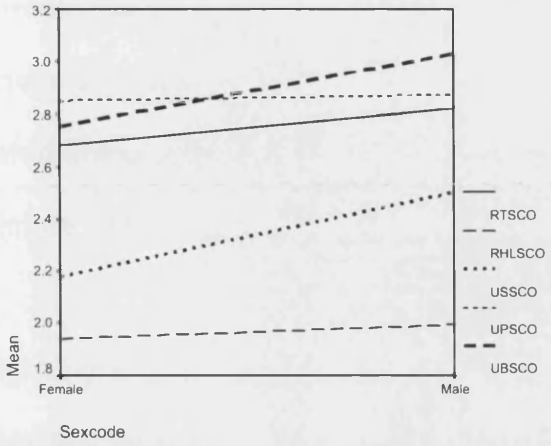
All but four rugosity scores differ significantly between males and females (Table 4.4). For all scores, the male mean is higher than the female mean, but for the tibia soleal line, ulna pronator, radial head wear and femur gluteal scores (TSSCO, UPSCO, RHSCO, FGSCO), this difference is not significant (Table 4.3). The rugosity scores are independent of body size, so this sex difference must be due to genuine activity differences between the sexes in these populations.

Table 4.4 : Descriptive statistics for mean rugosity scores by sex

	Female			Male		
	Mean	S.D.	N	Mean	S.D.	N
TTSCO	2.51	.89	153	3.02	.92	170
TSSCO	2.54	.87	155	2.68	.78	175
FGSCO	3.22	.96	158	3.27	.96	182
FPSCO	2.48	.79	159	2.91	.76	182
USSCO	2.19	.75	158	2.47	.86	178
UPSCO	2.88	.86	151	2.91	.95	174
UBSCO	2.73	.66	158	3.01	.70	178
CWSCO	2.01	.77	137	2.26	.83	168
CSSCO	2.41	.87	143	2.94	.95	170
CDSCO	2.74	.74	148	2.95	.77	171
RTSCO	2.65	.86	154	2.84	.79	172
RHSCO	1.92	.76	144	1.97	.76	164
HDSCO	2.48	.99	159	2.80	1.04	179
HISCO	2.68	.85	155	2.97	.80	176

Graph 4.2: Summary of sex differences in rugosity patterning

a. ulna and radius, b. humerus and clavicle, c. tibia and femur



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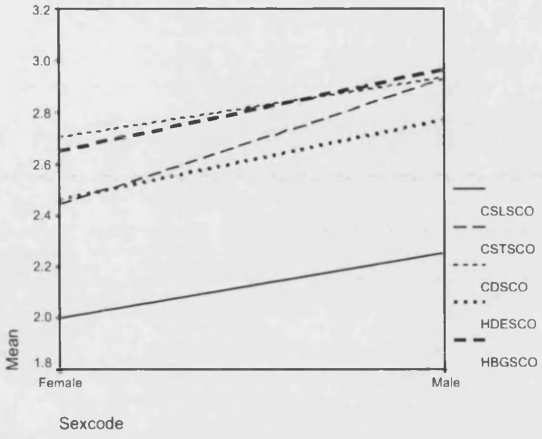

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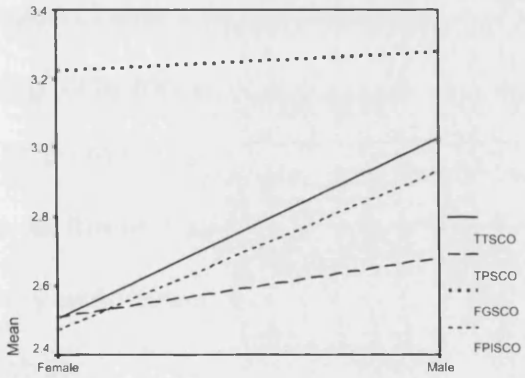


c

Score Legend

USSCO	Ulna supinator
UPSCO	Ulna pronator
UBSCO	Ulna brachialis
RTSCO	Radial tuberosity
RHLSCO	Radial head lipping
CSLSCO	Clavicle sternal lipping
CSSCO	Clavicle sternal ligament
CDSCO	Clavicle distal ligament
TTSCO	Tibial tuberosity
TPSCO	Tibia soleal line
FGSCO	Femur gluteal
FPSCO	Femur linea aspera
HDESCO	Humerus deltoid
HBGSCO	Humerus bicuspid groove

Climate

Climate has not traditionally been thought of as a determinant of surface rugosity, where age, sex and lifestyle may be more readily apparent as significant factors in determining activity patterns. However, given the interdependence of lifestyle with climate and continent, significant results are not unexpected.

Eight significant differences in rugosity scores are found between hot and temperate climates, three between temperate and cold climates, and five between hot and cold climates (Table 4.6). This demonstrates that extremes of temperature are not the driving force for producing rugosity differences, otherwise hot and cold climates would be the most different. Only one of the significant scores is found on the lower limb, all the rest are upper body scores, which implies that differences in manual activity associated with climatic regimes are important in determining rugosity variability.

Between hot and temperate climates, the mean values for all three ulna scores, the ligament attachments at the distal and sternal ends of the clavicle, the radial tuberosity score, the humerus deltoid score and the femur gluteal score differ significantly. In all cases, the temperate score is higher, so that individuals from hot climates appear less rugged across the body (Table 4.5).

Between temperate and cold climates, the ulna supinator score is significantly higher in temperate climates, but the ulna pronator and humerus deltoid scores are significantly higher in cold climate individuals. Between hot and cold climates, the

cold climate mean score is significantly higher in the ulna pronator, ulna brachialis, radial tuberosity, humerus deltoid and intertubercular groove scores.

Table 4.5 : Descriptive statistics for mean rugosity scores by climate

	hot			temperate			cold		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TTSCO	2.82	1.02	141	2.78	.93	140	2.65	.71	59
TPSCO	2.74	.87	145	2.55	.85	143	2.58	.70	63
FGSCO	3.01	.86	148	3.43	1.06	149	3.29	.95	65
FPISCO	2.67	.82	149	2.66	.83	149	2.89	.72	65
USSCO	2.17	.73	149	2.53	.88	143	2.22	.81	63
UPSCO	2.70	.95	147	3.01	.86	135	3.33	.86	61
UBSCO	2.72	.70	149	2.98	.70	143	3.02	.67	63
CSLSCO	2.08	.78	140	2.24	.84	127	2.21	.85	53
CSTSCO	2.56	.90	143	2.84	1.02	132	2.80	.90	58
CDSCO	2.68	.74	144	3.02	.77	137	2.81	.80	58
RTSCO	2.34	.72	143	3.04	.78	142	3.04	.82	62
RHLSCO	1.96	.70	139	1.94	.78	127	2.13	.94	56
HDESCO	2.46	1.00	148	2.65	1.07	146	3.24	.95	66
HBGSCO	2.52	.81	144	2.99	.78	144	3.13	.81	60

Summary

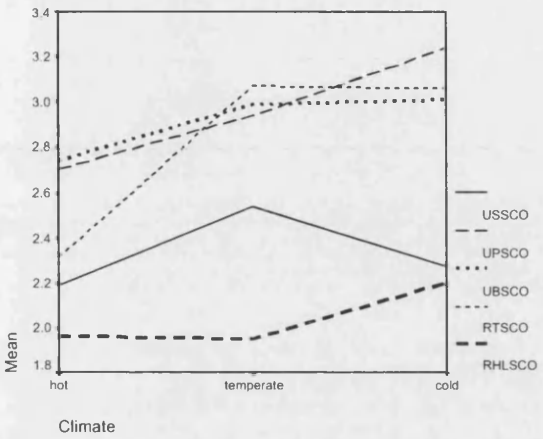
Hot climates, or activities associated with hot climates, exert the least surface stress on bones. Temperate climates, or activities associated with temperate climates, produce higher scores especially in the femur gluteal region, the clavicle and ulna supinator. Cold climates are associated with higher scores at the ulna brachialis and humerus deltoid. Although temperate and cold climates are both associated with higher rugosity scores, compared with hot climates, the effects are shown in different regions of the body (Figure 4.3).

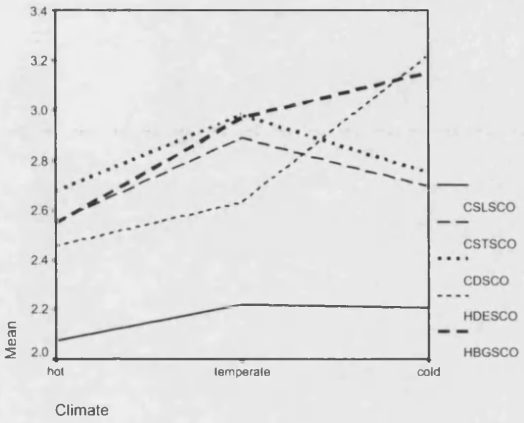
Table 4.6 : Kruskal-Wallis test of climate differences in postcranial scores

	TTSCO	TPSCO	USSCO	UPSCO	UBSCO	CSLSCO	CSTSCO	CDSCO	RTSCO	RHLSCO	HDESCO	HBGSCO	FGSCO	FPISCO
Hot/Temp.														
Chi-Square	.001	3.268	12.998	6.417	10.906	3.492	4.853	14.091	54.230	.074	1.830	23.330	11.406	.002
df	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.976	.071	.000*	.011*	.001*	.062	.028*	.000*	.000*	.786	.176	.000*	.001*	.963
Temp./Cold														
Chi-Square	1.030	.080	4.398	5.375	.034	.063	.059	2.477	.209	1.228	13.743	1.455	.863	3.252
df	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.310	.778	.036*	.020*	.854	.801	.808	.116	.648	.268	.000*	.228	.353	.071
Hot/Cold														
Chi-Square	.659	1.662	.313	17.000	8.431	1.135	2.666	1.202	28.841	.952	23.173	21.315	3.227	3.579
df	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.417	.197	.576	.000*	.004*	.287	.103	.273	.000*	.329	.000*	.000*	.072	.059
All														
Chi-Square	.981	3.718	13.442	18.690	14.075	3.625	5.641	13.794	61.717	1.341	23.408	32.735	11.786	4.031
df	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.612	.156	.001*	.000*	.001*	.163	.060	.001*	.000*	.511	.000*	.000*	.003*	.133

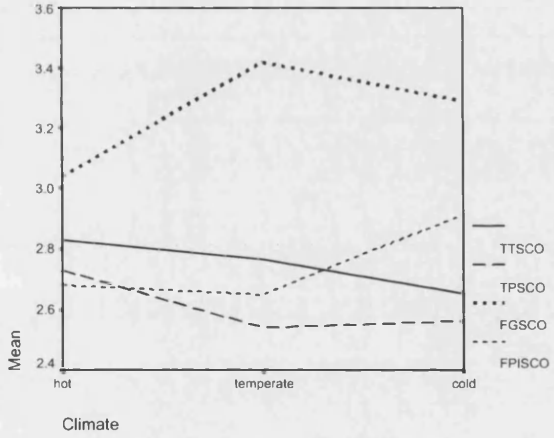
Figure 4.3 : Summary of climate differences in rugosity patterning

a. ulna and radius, b. humerus and clavicle, c. tibia and femur





a



b

Score Legend

USSCO	Ulna supinator
UPSCO	Ulna pronator
UBSCO	Ulna brachialis
RTSCO	Radial tuberosity
RHLSCO	Radial head lipping
CSLSCO	Clavicle sternal lipping
CSSCO	Clavicle sternal ligament
CDSCO	Clavicle distal ligament
TTSCO	Tibial tuberosity
TPSCO	Tibia soleal line
FGSCO	Femur gluteal
FPSCO	Femur linea aspera
HDESCO	Humerus deltoid
HBGSCO	Humerus bicuspid groove

c

Lifestyle

The pattern of significant results become more complex in comparisons between pairs of lifestyle categories. All lifestyle categories differ significantly from all others, but the regions in which they show significant differences in rugosity vary from pair to pair. Radial head wear score does not vary with lifestyle in any comparisons.

The hunt/fish and hunt/gather categories are the most similar, differing significantly only in ulna pronator and radial tuberosity scores (Table 4.8). Hunt/fish people are more rugged in these regions, and presumably are doing more twisting and pulling with the forearms. This could be explained by hauling nets or sea mammal carcasses, by food preparation, or by rowing.

The pattern of rugosity across the body is very different between hunt/herd people and hunt/fish people (Table 4.8). The scores that are significantly higher in hunt/herd people are the ulna supinator, clavicle wear, clavicle distal ligaments, and radial tuberosity, which are upper body regions perhaps associated with riding, hunting or other herding activities. The tibial tuberosity, humerus deltoid and femur pilaster mean scores are higher in hunt/fish people, and suggest general locomotion stresses and heavy work with the upper arm.

Compared with agriculturalists, hunt/fish people have significantly higher mean scores only in the humerus deltoid (Table 4.7). The agricultural strategy produces

significantly higher mean scores in the ulna brachialis, clavicle sternal wear score and distal ligament attachment, and femur gluteal score.

Hunt/fish people have higher mean rugosity scores than cultivate/hunt people in the ulna pronator and humerus deltoid, a pattern seen in comparisons above. However, the cultivate/hunt mean score is higher in the tibial tuberosity, and femur gluteal and linea aspera scores. This lifestyle category shows the highest mean score in the sample for these three scores, and demonstrates high locomotor stresses deriving from activities associated with this subsistence regime. The cause may be long diurnal ranges for hunting or combinations of postural and weight bearing strains associated with cultivation.

Table 4.7 : Summary of mean rugosity scores by lifestyle

	hunt/fish			hunt/gather			hunt/herd			cultivate/hunt			agriculture		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TTSCO	2.67	.73	102	2.83	1.20	30	2.10	.91	44	3.19	.83	81	2.85	.96	83
TPSCO	2.59	.73	106	2.75	.83	33	2.45	.82	46	2.79	.88	81	2.59	.92	85
FGSCO	3.05	.94	113	3.23	.83	33	2.84	1.15	45	3.74	.99	83	3.18	.78	88
FPISCO	2.67	.72	113	2.87	.91	33	2.23	.87	45	2.90	.75	83	2.75	.83	89
USSCO	2.17	.76	109	2.20	.87	33	2.67	1.04	46	2.32	.66	80	2.39	.82	87
UPSCO	3.15	.83	105	2.38	1.23	32	3.11	.87	40	2.53	.75	80	3.17	.90	86
UBSCO	2.75	.65	109	2.77	.86	33	2.89	.84	46	2.86	.56	80	3.08	.73	87
CSLSCO	2.04	.78	98	2.09	.81	29	2.41	.76	43	1.95	.80	73	2.42	.81	77
CSTSCO	2.71	.93	103	3.05	1.09	31	2.49	1.03	44	2.91	.77	74	2.53	.99	81
CDSCO	2.71	.77	105	2.86	.94	31	2.94	.75	44	2.76	.65	76	3.02	.80	83
RTSCO	2.83	.75	106	2.29	.97	31	3.12	.79	45	2.67	.78	78	2.70	.87	87
RHLSCO	1.99	.85	101	1.89	.68	27	2.00	1.02	36	1.99	.68	78	1.98	.69	80
HDESCO	3.05	1.19	113	2.95	.98	33	2.45	1.07	46	2.39	.90	80	2.50	.87	88
HBGSCO	2.83	1.00	108	2.88	.65	29	2.92	.71	45	2.60	.74	80	2.94	.79	86

Table 4.8: Kruskal-Wallis test of lifestyle differences in postcranial scores

		TTSCO	TPSCO	USSCO	UPSCO	UBSCO	CSLSCO	CSTSCO	CDSCO	RTSCO	RHLSCO	HDESCO	HBGSCO	FGSCO	FPISCO
HF/HG	Chi-Square	.328	.380	.068	12.479	.015	.092	2.584	.625	10.571	.130	.196	.186	.536	.854
1 df	Asymp. Sig.	.567	.538	.794	.000*	.901	.762	.108	.429	.001*	.718	.658	.666	.464	.356
HF/HH	Chi-Square	13.722	1.700	7.708	.029	1.184	8.671	1.880	4.292	4.097	.081	7.929	.756	2.882	8.434
1 df	Asymp. Sig.	.000*	.192	.005*	.864	.277	.003*	.170	.038*	.043*	.776	.005*	.384	.090	.004*
HF/CH	Chi-Square	17.214	1.970	1.577	23.204	1.326	.610	2.931	.801	1.313	.131	15.489	2.172	21.781	4.559
1 df	Asymp. Sig.	.000*	.160	.209	.000*	.249	.435	.087	.371	.252	.717	.000*	.141	.000*	.033*
HF/AG	Chi-Square	1.399	.007	2.442	.022	9.043	9.744	1.341	7.979	1.460	.021	11.959	.991	.981	.502
1 df	Asymp. Sig.	.237	.935	.118	.882	.003*	.002*	.247	.005*	.227	.884	.001*	.319	.322	.479
HG/HH	Chi-Square	6.485	2.257	4.691	8.240	.502	3.239	5.040	.420	15.011	.003	4.075	.140	3.907	7.570
1 df	Asymp. Sig.	.011*	.133	.030*	.004*	.479	.072	.025*	.517	.000*	.960	.044*	.708	.048*	.006*
HG/CH	Chi-Square	2.091	.171	1.880	1.539	.752	.666	.336	.115	5.572	.432	8.196	2.827	7.307	.154
1 df	Asymp. Sig.	.148	.679	.170	.215	.386	.414	.562	.734	.018*	.511	.004*	.093	.007*	.695
HG/AG	Chi-Square	.020	.427	1.885	11.928	3.582	3.335	4.866	.991	5.077	.193	6.461	.126	.011	.167
1 df	Asymp. Sig.	.887	.513	.170	.001*	.058	.068	.027*	.319	.024*	.660	.011*	.723	.917	.682
HH/CH	Chi-Square	32.264	4.859	3.495	13.221	.172	9.854	6.489	2.552	7.465	.309	.083	5.521	17.642	16.756
1 df	Asymp. Sig.	.000*	.028*	.062	.000*	.678	.002*	.011*	.110	.006*	.578	.773	.019*	.000*	.000*
HH/AG	Chi-Square	15.747	.943	2.302	.074	1.391	.045	.194	.183	6.938	.173	.025	.000	5.168	9.846
1 df	Asymp. Sig.	.000*	.331	.129	.785	.238	.832	.659	.669	.008*	.678	.873	.990	.023*	.002*
CH/AG	Chi-Square	5.758	1.593	.058	21.012	3.872	12.404	6.781	4.950	.007	.119	.670	6.925	15.585	1.731
1 df	Asymp. Sig.	.016*	.207	.809	.000*	.049*	.000*	.009*	.026*	.934	.730	.413	.009*	.000*	.188
All	Chi-Square	38.314	5.497	10.022	38.347	10.151	21.000	12.572	10.693	19.602	.601	24.535	8.324	32.134	18.875
4 df	Asymp. Sig.	.000*	.240	.040*	.000*	.038*	.000*	.014*	.030*	.001*	.963	.000*	.080	.000*	.001*

* = p <.05 HF: Hunt/fish, HG: Hunt/gather, HH: Hunt/herd, CH: Cultivate/hunt, AG: Agriculture, All: Whole sample

The hunt/gather strategy is very different in rugosity patterning to the hunt/herd strategy. The hunt/gather people have a higher mean score in tibial tuberosity, clavicle sternal ligament attachment, humerus deltoid and both femoral scores. The hunt/herd strategy produces higher mean scores in the ulna supinator and pronator, and the radial tuberosity. Hunt/gather people appear generally more rugged, except in the forearm. The cultivate/hunt strategy, compared with hunt/gather people, produces significantly higher mean scores in the radial tuberosity and femur gluteal score. In this comparison, hunt/gather people have significantly higher mean scores at the humerus deltoid.

Agriculturalists differ significantly from hunt/gather people in mean rugosity scores for ulna pronator, clavicle sternal ligament, radial tuberosity and humerus deltoid scores. The agriculturalist mean is higher for all these except the humerus deltoid. These two lifestyle strategies are frequently cited as being examples of opposite approaches to human subsistence, yet there are few significant differences in the rugosity morphology associated with them. Agricultural and cultivate/hunt strategies differ significantly in many more skeletal regions. The agriculturalist strategy produces significantly higher mean scores for the ulna pronator and brachialis, the clavicle distal ligament and sternal wear score and the humerus intertubercular groove. The cultivate/hunt strategy is significantly more rugged in the tibial tuberosity, the sternal ligament attachment of the clavicle, and the femur gluteal score.

Four rugosity scores differ significantly between the agricultural and hunt/herd strategies. Tibial tuberosity, femur gluteal and linea aspera scores are significantly higher in agriculturalists, while radial tuberosity score is higher in the hunt/herd group (Table 4.7). The most significant differences in a pairwise comparison are between hunt/herd and cultivate/hunt categories (Table 4.8). Five are significantly more rugged in the cultivate/hunt group, these being tibial tuberosity and soleal line scores, clavicle sternal ligament score, and femur gluteal and linea aspera scores. Four are significantly more rugged in the hunt/herd group, these being ulna pronator, clavicle sternal lipping wear, radial tuberosity and humerus intertubercular groove scores. The hunt/herd strategy is characterised by strong upper limb rugosity but low lower limb rugosity. The reverse is true for cultivate/hunt people, and the difference may be due to use of animals for load carrying or as riding animals, in hunt/herd groups.

Summary

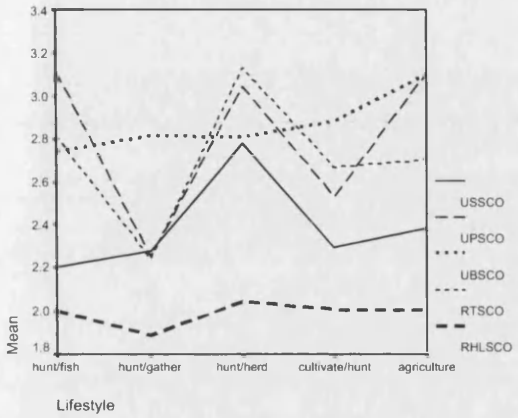
There are complex differences between lifestyle categories in postcranial rugosity. The hunt/gather and hunt/fish strategies are similar in rugosity patterning, with both categories being intermediate for leg rugosity, and high for upper arm and shoulder rugosity and wear (Figure 4.4). The forearm is more variable, with the hunt/fish group having higher radial tuberosity and ulna pronator scores. For forearm wear (radial head score) the hunt/gather group shows the lowest score.

The agricultural category is also intermediate in most scores, and has a similar profile to the hunt/gather or hunt/fish category. Hunt/herd people have high forearm rugosity and low leg rugosity, while the opposite is the case for cultivate/hunt people. In the upper arm, the pattern is mixed, but hunt/herd people show high humerus deltoid rugosity and clavicle distal rugosity, while the cultivate/hunt people show low clavicle wear and high clavicle sternal rugosity.

The rugosity patterning of the lower limb is much simpler with respect to lifestyle than the upper limb and shoulder (Figure 4.4). Scores are generally highest in the cultivate/hunt category, lower in the agricultural and hunt/gather categories, lower still in the hunt/fish group and lowest for hunt/herd people. In the upper arm and shoulder, the wear score for the clavicle sternal lipping facet behaves very differently to the rest of the scores, highlighting that it is indeed recording a different kind of information.

Figure 4.4: Summary of lifestyle differences in rugosity patterning

a. ulna and radius, b. humerus and clavicle, c. tibia and femur



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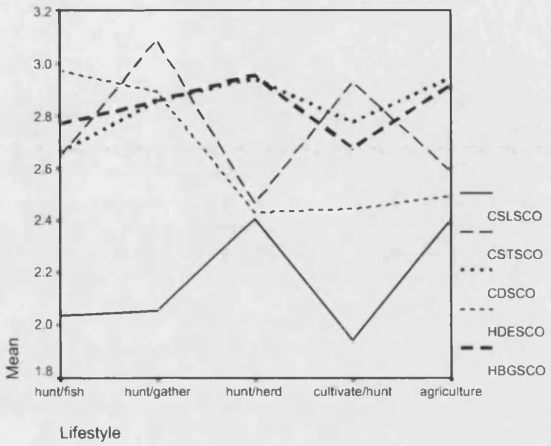

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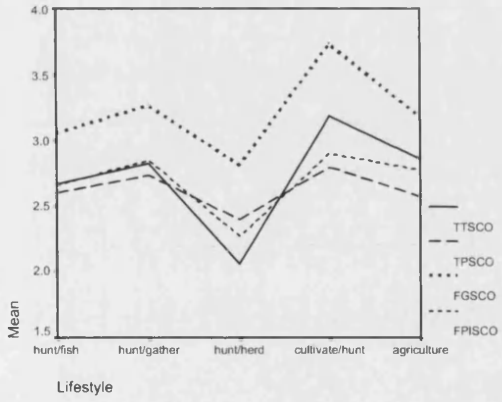


c

Score Legend

USSCO	Ulna supinator
UPSCO	Ulna pronator
UBSCO	Ulna brachialis
RTSCO	Radial tuberosity
RHLSCO	Radial head lipping
CSLSCO	Clavicle sternal lipping
CSSCO	Clavicle sternal ligament
CDSCO	Clavicle distal ligament
TTSCO	Tibial tuberosity
TPSCO	Tibia soleal line
FGSCO	Femur gluteal
FPSCO	Femur linea aspera
HDESCO	Humerus deltoid
HBGSCO	Humerus bicuspid groove

Continent

The pattern of significant results for rugosity score by continent is as complex as the pattern by lifestyle (Table 4.10). Each continent differs from each other continent at between two and nine different points.

Table 4.9: Summary of mean rugosity scores by continent

	Africa			Europe			Americas			Asia			Australasia		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
TTSCO	2.66	1.04	70	2.49	1.02	79	2.96	.76	132	2.72	.84	40	3.24	1.10	19
TSSCO	2.73	.89	73	2.46	.89	82	2.67	.72	135	2.65	.96	42	2.68	.76	19
FGSCO	3.08	.74	74	2.95	1.02	83	3.68	.91	142	2.64	1.00	44	3.13	.70	19
FPSCO	2.70	.82	75	2.43	.89	83	2.96	.69	142	2.39	.73	44	2.74	.86	19
USSCO	2.17	.69	76	2.67	.96	81	2.28	.74	136	2.10	.76	43	2.29	.98	19
UPSCO	2.70	1.04	74	3.23	.86	75	3.01	.85	132	2.95	.83	43	2.05	.80	19
UBSCO	2.83	.77	76	2.98	.77	81	2.90	.58	136	2.66	.80	43	2.97	.70	19
CWSCO	2.29	.79	67	2.41	.82	70	1.98	.78	122	2.20	.86	42	1.84	.69	19
CSSCO	2.34	.84	70	2.53	1.05	74	2.97	.85	127	2.63	.93	43	3.18	1.07	19
CDSCO	2.83	.75	70	3.01	.86	76	2.84	.73	131	2.60	.66	43	2.79	.95	19
RTSCO	2.23	.72	73	3.10	.82	81	2.90	.77	134	2.61	.86	42	2.44	.58	17
RHSCO	2.02	.61	70	1.92	.92	66	2.01	.77	129	2.00	.76	40	1.79	.92	17
HDSCO	2.37	.94	76	2.49	.94	82	3.04	1.07	141	2.52	1.10	42	2.53	1.14	19
HISCO	2.62	.84	73	2.96	.73	80	3.07	.83	136	2.26	.74	41	2.42	.60	18

The African populations differ significantly from the Europeans in tibia soleal score, ulna supinator and pronator score, radial tuberosity score, humerus intertubercular groove score and femur pilaster score. The European mean score is highest for all but the tibia soleal and femur pilaster scores, where the African mean is significantly higher (Table 4.9). Compared with the American populations, the Africans have significantly higher mean score at the clavicle sternal wear position. However, the American mean score is significantly higher for the tibia tuberosity, ulna pronator, clavicle sternal ligament attachment, radial tuberosity, humerus deltoid and

intertubercular groove, and femur gluteal and linea aspera scores. Compared with the Asian populations, the African mean is significantly higher for the humerus intertubercular groove, femur gluteal and linea aspera scores, but significantly lower for the radial tuberosity. Compared with the Australasian populations, the African mean is significantly higher for the ulna pronator and clavicle sternal lipping score, but significantly lower for the tibial tuberosity and clavicle sternal ligament attachment scores (Table 4.9).

The European populations show eight significant differences compared with the Americans. The American mean is significantly higher in the tibial tuberosity and soleal line scores, in the clavicle sternal ligament attachment, the humerus deltoid and the femur gluteal and linea aspera scores. The European mean is significantly higher in the ulna supinator and clavicle sternal lipping scores. Compared to the Asian populations, the European mean is significantly higher at the ulna supinator, ulna brachialis, clavicle distal ligament, radial tuberosity and humerus intertubercular groove. No rugosity scores are significantly higher in the Asian populations. Compared to the Australasian populations, the European mean is significantly higher in the scores for ulna pronator, clavicle sternal lipping, radial tuberosity and humerus intertubercular groove. The Australasian mean is significantly higher in the scores for tibia tuberosity and clavicle sternal ligament attachment.

Table 4.10 : Kruskal-Wallis test of continent differences in postcranial scores

		TTSCO	TPSCO	USSCO	UPSCO	UBSCO	CSLSCO	CSTSCO	CDSCO	RTSCO	RHLSCO	HDESCO	HBGSCO	FGSCO	FPISCO
AF/EU	Chi-Square	.692	4.008	11.478	9.664	1.599	1.790	.517	2.072	38.870	2.398	1.035	7.604	1.463	4.182
1 d.f.	Asymp. Sig.	.406	.045*	.001*	.002*	.206	.181	.472	.150	.000*	.122	.309	.006*	.227	.041*
AF/AM	Chi-Square	6.676	.316	1.392	4.213	.718	5.691	20.962	.008	33.980	.034	18.294	12.861	21.159	5.400
1 d.f.	Asymp. Sig.	.010*	.574	.238	.040*	.397	.017*	.000*	.929	.000*	.853	.000*	.000*	.000*	.020*
AF/AS	Chi-Square	.344	.239	.177	1.562	1.417	.348	2.551	1.645	4.959	.019	.610	4.489	6.236	4.657
1 d.f.	Asymp. Sig.	.557	.625	.674	.211	.234	.555	.110	.200	.026*	.891	.435	.034*	.013*	.031*
AF/AU	Chi-Square	4.449	.129	.002	6.528	.561	4.806	8.156	.148	.931	3.472	.397	.612	.077	.005
1 d.f.	Asymp. Sig.	.035*	.720	.966	.011*	.454	.028*	.004*	.700	.335	.062	.529	.434	.782	.946
EU/AM	Chi-Square	12.122	4.562	8.130	3.206	.882	12.562	10.586	2.611	3.704	1.611	11.954	.610	27.218	22.191
1 d.f.	Asymp. Sig.	.000*	.033*	.004*	.073	.348	.000*	.001*	.106	.054	.204	.001*	.435	.000*	.000*
EU/AS	Chi-Square	1.607	1.237	9.650	3.132	5.113	2.718	.391	6.331	10.303	.847	.025	20.795	1.908	.098
1 d.f.	Asymp. Sig.	.205	.266	.002*	.077	.024*	.099	.532	.012*	.001*	.357	.875	.000*	.167	.754
EU/AU	Chi-Square	6.887	1.451	3.263	21.885	.003	7.437	5.303	1.355	11.123	.320	.010	8.072	1.001	1.723
1 d.f.	Asymp. Sig.	.009*	.228	.071	.000*	.953	.006*	.021*	.244	.001*	.572	.919	.004*	.317	.189
AM/AS	Chi-Square	2.857	.050	1.760	.185	5.101	1.760	3.866	2.340	5.208	.002	6.184	26.487	32.342	20.010
1 d.f.	Asymp. Sig.	.091	.822	.185	.667	.024*	.185	.049*	.126	.022*	.968	.013*	.000*	.000*	.000*
AM/AU	Chi-Square	1.654	.016	.280	17.924	.090	.499	.309	.224	7.919	2.070	3.085	9.863	6.511	2.397
1 d.f.	Asymp. Sig.	.198	.901	.597	.000*	.764	.480	.578	.636	.005*	.150	.079	.002*	.011*	.122
AS/AU	Chi-Square	3.557	.009	.177	13.133	2.644	2.368	2.997	.173	.654	1.637	.002	.881	4.180	2.323
1 d.f.	Asymp. Sig.	.059	.924	.674	.000*	.104	.124	.083	.678	.419	.201	.969	.348	.041*	.127
ALL	Chi-Square	18.234	5.734	16.362	28.418	7.120	17.709	26.314	7.036	54.735	4.482	23.744	40.659	53.038	32.456
4 d.f.	Asymp. Sig.	.001*	.220	.003*	.000*	.130	.001*	.000*	.134	.000*	.345	.000*	.000*	.000*	.000*

* = $p < .05$ AF: Africa, EU: Europe, AM: Americas, AS: Asia, AU: Australasia, ALL: Whole sample

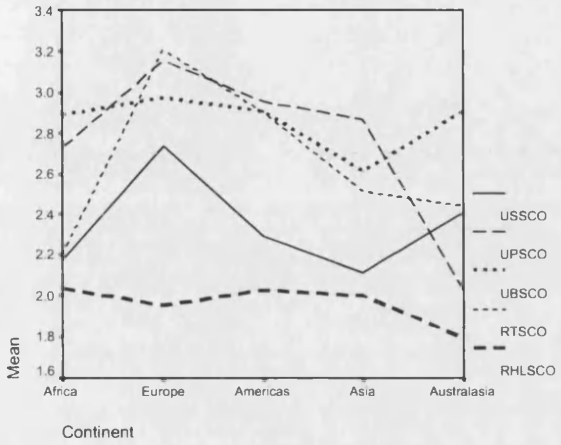
The American populations show seven significant differences compared with the Asian population, in all cases the American mean is higher. The scores are for ulna brachialis, clavicle sternal ligament, radial tuberosity, humerus deltoid and intertubercular groove, and femur gluteal and linea aspera. Compared with the Australasian populations, there are three significant difference, again with the American mean being significantly higher. These scores are for ulna pronator, humerus intertubercular groove and femur gluteal score. The Australasian and Asian populations differ the least, having just two points of significant difference between them. The ulna pronator score is higher in the Asians, and the femur gluteal score is higher in the Australasians.

Summary

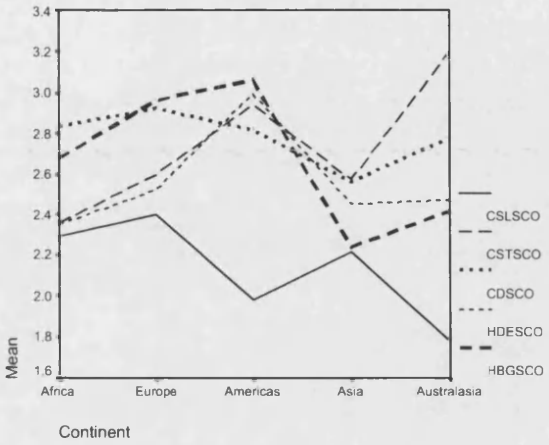
The scores for the lower limb behave in a similar way to each other relative to continent (Figure 4.5b), while the upper limb and shoulder scores are more variable in patterning (Figures 4.5a and 4.5c). Australasia shows very low mean scores for the two wear scores, the radial head lipping and clavicle sternal lipping scores, but in general, the Asian populations are positioned low on all scores. The Europeans are positioned high on all the forearm scores except that for radial head wear or lipping, with the African and American populations coming close to this position. However, the Americans are positioned high on the leg scores, with Africa and Australasian the next highest. The American and Australasian populations rank higher on the humerus and clavicle scores, with the exception of the clavicle sternal wear or lipping score.

Figure 4.5: Summary of continent differences in rugosity patterning

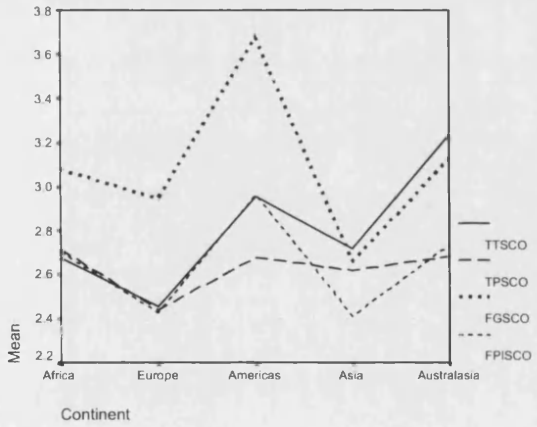
a. ulna and radius, b. humerus and clavicle, c. tibia and femur



a



b



c

Score Legend

USSCO	Ulna supinator
UPSCO	Ulna pronator
UBSCO	Ulna brachialis
RTSCO	Radial tuberosity
RHLSCO	Radial head lipping
CSLSCO	Clavicle sternal lipping
CSSCO	Clavicle sternal ligament
CDSCO	Clavicle distal ligament
TTSCO	Tibial tuberosity
TPSCO	Tibia soleal line
FGSCO	Femur gluteal
FPSCO	Femur linea aspera
HDESCO	Humerus deltoid
HBGSCO	Humerus bicuspid groove

Five-way ANOVA

Table 4.11 : Summary of five-way ANOVA results

	TTSCO					TSSCO			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	150.966	246			none	149.079	251		
age	191.513	286	1.091	ns	age	183.274	291	1.060	ns
sex	204.193	280	1.188	ns	sex	187.291	285	1.106	ns
climate	160.636	260	1.007	ns	climate	153.574	265	0.976	ns
lifestyle	178.249	270	1.076	ns	lifestyle	175.395	275	1.074	ns
continent	163.154	262	1.015	ns	continent	166.002	267	1.047	ns

	USSCO					UBSCO			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	151.828	254			none	106.167	254		
age	182.544	295	1.035	ns	age	124.86	295	1.013	ns
sex	183.374	288	1.065	ns	sex	128.394	288	1.067	ns
climate	160.23	270	0.993	ns	climate	113.234	270	1.003	ns
lifestyle	165.582	280	0.989	ns	lifestyle	124.628	280	1.065	ns
continent	162.014	271	1.000	ns	continent	115.516	271	1.020	ns

	UPSCO					CDSCO			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	158.878	243			none	120.253	241		
age	191.035	284	1.029	ns	age	143.972	281	1.027	ns
sex	175.539	277	0.969	ns	sex	143.847	274	1.052	ns
climate	165.484	259	0.977	ns	climate	131.426	256	1.029	ns
lifestyle	196.025	269	1.115	ns	lifestyle	135.109	267	1.014	ns
continent	174.681	260	1.028	ns	continent	125.372	258	0.974	ns

	CSSCO					CWSCO			
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	159.032	235			none	115.576	228		
age	187.682	275	1.008	ns	age	148.838	268	1.096	ns
sex	202.727	268	1.118	ns	sex	137.034	261	1.036	ns
climate	173.096	250	1.023	ns	climate	125.577	243	1.019	ns
lifestyle	184.546	261	1.045	ns	lifestyle	131.756	254	1.023	ns
continent	184.076	252	1.079	ns	continent	131.831	245	1.061	ns

Table 4.11:
continued

RHSCO					RTSCO				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	118.922	232			none	116.745	243		
age	154.124	272	1.105	**ns**	age	152.484	288	1.102	**ns**
sex	138.464	266	1.016	**ns**	sex	139.727	282	1.031	**ns**
climate	133.329	247	1.053	**ns**	climate	134.675	263	1.066	**ns**
lifestyle	137.989	256	1.052	**ns**	lifestyle	136.767	272	1.047	**ns**
continent	126.150	247	0.996	**ns**	continent	129.000	263	1.021	**ns**
HISCO					**HDSCO**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	110.736	254			none	209.701	254		
age	136.294	295	1.060	**ns**	age	246.653	298	1.003	**ns**
sex	131.794	288	1.050	**ns**	sex	239.993	291	0.999	**ns**
climate	138.471	269	1.181	**ns**	climate	239.521	272	1.067	**ns**
lifestyle	150.344	279	1.236	**ns**	lifestyle	258.913	282	1.112	**ns**
continent	127.931	270	1.087	**ns**	continent	231.919	273	1.029	**ns**
FPSCO					**FGSCO**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	124.032	258			none	151.385	257		
age	151.132	299	1.051	**ns**	age	195.132	298	1.112	**ns**
sex	169.574	292	1.208	**ns**	sex	169.574	291	0.989	**ns**
climate	194.841	274	1.479	**0.05**	climate	194.841	273	1.212	**ns**
lifestyle	176.745	284	1.295	**0.01**	lifestyle	176.745	283	1.060	**ns**
continent	170.675	275	1.291	**0.01**	continent	170.675	274	1.057	**ns**

The five-way ANOVA revealed very few significant results between categories, once all other categories were held constant (Table 4.11). The only score to show any significant results is the femur pilaster score, which shows a significant influence of climate, lifestyle and continent, when other categories are held stable. The humerus intertubercular score approaches significance for comparisons between lifestyle, where other categories are held constant.

The femur pilaster score (FPSCO) has lower variance than most scores, and so the significant influences of climate, lifestyle and continent are not because it is inherently more variable (Table 4.12). Posture, terrain and locomotor activity differences must therefore play a strong role in determining the morphology of this muscle attachment. There are several muscles attaching along this crest, involved in hip adduction and knee flexion. Climate, subsistence strategy and continent influence the range of activities in which these muscles are involved, such as riding, squatting, cultivation and walking over rough terrain.

Table 4.12: Descriptive statistics for the postcranial scores, whole sample

	N	Mean	Std. Deviation	Variance
FGSCO	359	3.2354	.9779	.956
FPSCO	360	2.7021	.8131	.661
HDSCO	357	2.6807	1.0516	1.106
HISCO	348	2.8204	.8360	.699
TTSCO	340	2.7765	.9360	.876
TSSCO	348	2.6300	.8346	.696
USSCO	352	2.3295	.8196	.672
UPSCO	341	2.9406	.9237	.853
UBSCO	352	2.8828	.7035	.495
CWSCO	320	2.1625	.8144	.663
CSSCO	331	2.7122	.9577	.917
CDSCO	337	2.8405	.7613	.580
RTSCO	344	2.7522	.8364	.700
RHSCO	322	1.9814	.7772	.604

Interactions between categories

There is considerable evidence for interactions between the categories in their influence on postcranial scores (Table 4.13). Significant interactions between two, three or four categories are listed for each postcranial scored variable. Column headings refer to the categories included in the four- or five-way analysis. All multi-way analyses use a full factorial model. A significant interaction implies that the categories do not vary randomly with respect to one another. For example, for tibia tuberosity score (TTSCO) in the five-way analysis, age and climate show significant interaction. This means that the age-related variation in tibia tuberosity score differs between climatic zones. This further implies a climatic influence on age-specific activities involving the lower leg.

The most common interactions are between age or sex and one of the other three categories. Age and sex are expected to be strong determinants of individual activity patterns, and that such age or sex specific activites should vary amongst climates, continents or lifestyles is also to be expected. Interaction between age and sex or between age, sex and either climate or lifestyle is also common. This reinforces the argument that individual activities are determined mainly by age and sex.

Climate and continent show significant interaction for several rugosity scores (TTSCO, UBSCO, CSSCO, HBSCO, FPSCO and FGSCO), all in the analyses where the lifestyle category is omitted (Table 4.13). This suggests that the climatic influence on rugosity at these points in the skeleton is altered by the continent on which the people live. Since lifestyle is omitted in these analyses, the assumption that this indicates a genetic difference cannot be drawn. As noted above, the climatic categories are not spread evenly across the continents, since some continents do not contain all three climatic zones.

Climate and lifestyle also show significant interactions for several rugosity scores, (UPSCO, CCSCO, HBSCO, HDSCO, FPSCO and FGSCO), where the continent category is omitted. These findings indicate that the effects of climate and lifestyle are interdependent, and do not vary randomly with respect to one another. This is to be expected, since the activities habitual for a certain subsistence strategy may be influenced by the climate. This suggests further that lifestyle categories may be more accurate where they take climatic zone into account. Hunt/herd people in sub-Arctic zones, for example, are likely to have different activity requirements to hunt/herd people in sub-tropical zones.

Table 4.13 : Summary of interaction effects on postcranial scores.

PC Score	All Categories	Minus age	Minus sex	Minus Climate	Minus Lifestyle	Minus Continent
TTSCO	age x climate *				age x climate ** climate x continent * sex x continent *	age x climate * age x lifestyle *
TPSCO	sex x continent ** sex x lifestyle * age x sex x lifestyle *	sex x continent *		age x sex * age x lifestyle * age x continent * age x sex x continent * age x sex x lifestyle ** sex x lifestyle x continent **	age x sex x climate x continent *	age x sex x lifestyle *
USSCO						sex x lifestyle *
UBSCO	age x sex x lifestyle * age x sex x continent *	lifestyle x continent *		lifestyle x continent *	climate x continent *	
UPSCO			age x lifestyle *	age x lifestyle * lifestyle x continent *		climate x lifestyle **
CDSCO			age x climate **		sex x continent ** age x sex x continent *	sex x lifestyle **
CSSCO		sex x lifestyle *			climate x continent *	climate x lifestyle *
CLSCO	age x continent *	lifestyle x continent **	age x continent *	age x lifestyle x continent *		
RTSCO	age x climate *		age x climate ** age x lifestyle **	age x sex x continent *	age x climate ** sex x climate **	age x climate ** age x lifestyle * age x sex x climate * age x sex x climate x lifestyle *
RHSCO						
HBSCO	age x sex x climate *				age x sex x climate * climate x continent **	climate x lifestyle **

Table 4.13 : continued

PC Score	All Categories	Minus age	Minus sex	Minus Climate	Minus Lifestyle	Minus Continent
HDSCO	age x sex *		age x climate * age x continent *	lifestyle x continent *	age x sex x climate **	climate x lifestyle ** age x sex x climate **
FPSCO		sex x lifestyle *			climate x continent **	climate x lifestyle *
FGSCO					climate x continent **	climate x lifestyle * sex x climate x lifestyle *

* = p < .05 ** = p < .01

Principal Components Analysis

A principal component analysis, utilising varimax rotation and converging in six rotations, extracted four components from the list of all postcranial scores (Table 4.14). 263 individuals had all the required variables; the rest were excluded. The four components accounted for only 53% of the cumulative variance. The components split the variables into forearm, leg, upper arm and wear scores respectively. The variables identified in the table all loaded strongly and positively on the component with which they are identified.

The clavicle distal ligament score falls with the majority of forearm scores suggesting that it is stressed during forearm activities. The ulna pronator score falls with the two humeral scores, suggesting that this muscle on the ulna is utilised with upper arm activities, for example, lifting, carrying and certain postures associated with weapon or cultivation tool use. Of the ulna scores, brachialis might have been expected to fall with the humeral scores, given that the muscle attachment it assesses has its origin on the upper arm. Equally, the clavicle distal ligament might be expected to fall with the humeral scores, rather than the forearm scores. Activity-based loading on the arm and shoulder is likely to affect the whole region, since the forearm and upper arm are rarely loaded entirely independently of the other arm component. This grouping of the rugosity variables suggests that there may be two alternative configurations of loading for the arm, utilising subtly different muscle complexes.

Table 4.14: Variable loading and variance explained: PCA for postcranial scores

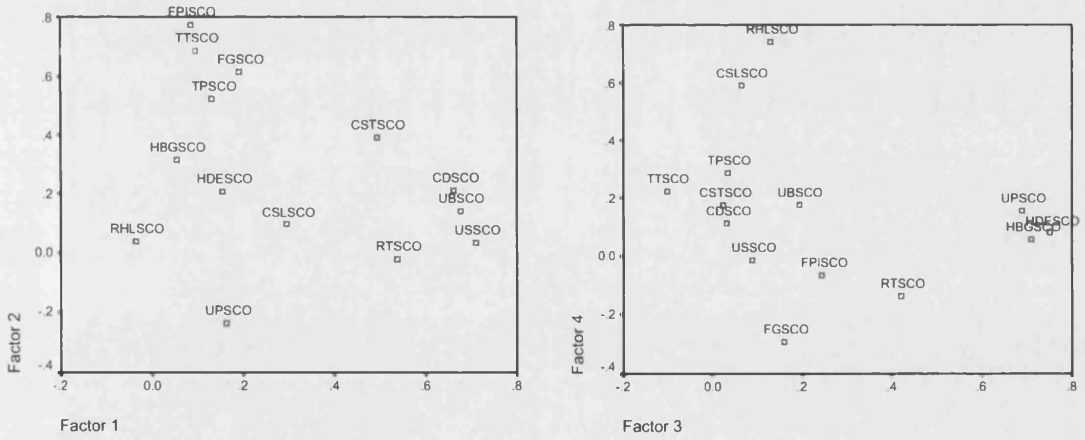
	Major Loaded Variables (over .5)	**Component Summary**	**Rotation Sums of Squared Loadings**		
Component			Total	% of Variance	Cumulative %
1	ulna supinator ulna brachialis clavicle distal ligament *radial tuberosity* *clavicle sternal ligament*	Forearm rugosity	2.144	15.316	15.316
2	femur linea aspera tibia tuberosity femur gluteal tibia soleal line	Leg rugosity	2.139	15.280	30.595
3	humerus deltoid humerus intertubercular groove ulna pronator	Upper arm rugosity	1.888	13.485	44.081
4	radial head lipping clavicle sternal lipping	Upper body wear	1.252	8.943	53.024

Table 4.15: Rotated component matrix for postcranial scores: sorted by size

Component	**1**	**2**	**3**	**4**
USSCO	.710	.033	.089	-.013
UBSCO	.676	.139	.194	.178
CDSCO	.661	.211	.033	.114
RTSCO	.537	-.022	.422	-.136
CSTSCO	.493	.391	.024	.176
FPISCO	.086	.772	.244	-.067
TTSCO	.097	.685	-.103	.225
FGSCO	.192	.613	.162	-.293
TPSCO	.133	.521	.033	.288
HDESCO	.155	.207	.752	.079
HBGSCO	.054	.315	.710	.056
UPSCO	.163	-.236	.689	.155
RHLSCO	-.033	.036	.130	.742
CSLSCO	.296	.095	.064	.591

Repeated PCA runs using subsets of the variables produced no difference in how the variables grouped on the components, although variation in the percentage of variance explained produced some expected reversals of component order. Graphing these components by age, sex, climate, lifestyle, continent or population produced no separation of the categories. Producing age, sex and population specific mean PCA scores did not help to clarify the graphs. Individual idiosyncracies are therefore stronger than group characteristics in influencing component loading. When scores for each variable are plotted, no obvious clusters are discernable (Figure 4.6).

Figure 4.6: PCA on postcranial scores a. factors 1 and 2 by variable and b. factors 3 and 4 by variable



Clavicle sternal rugosity score and radial tuberosity score did not load significantly on any component, each being split evenly between two components. These variables will therefore be omitted from discriminant function analysis.

Summary of postcranial score analysis

These results highlight interesting differences in the ways different kinds of MSM behave in respect of underlying conditions. The Principal Components Analysis, as well as the single-category explorations using Kruskal-Wallis methods, indicate that rugosity scores relating to different regions of the body respond differently to demographic and ecological factors.

The high level of individual variance in rugosity is clear, supported by the low explanatory power of the PCA, and by the failure of five-way ANOVA to find many significant influences on rugosity scores. The multi-way ANOVAs demonstrate significant interdependence between categories, which further undermines attempts to distinguish individuals on the basis of single categories.

The implications are therefore that it is unwise to make global generalisations about rugosity based on age, sex, climate, lifestyle or continent. At smaller scales, such generalisations may well be warranted, however. Males are notably more rugged than females, but a highly rugged individual cannot be identified clearly as male. Furthermore, when other categories are held constant, in a five-way ANOVA, the significant difference between males and females disappears.

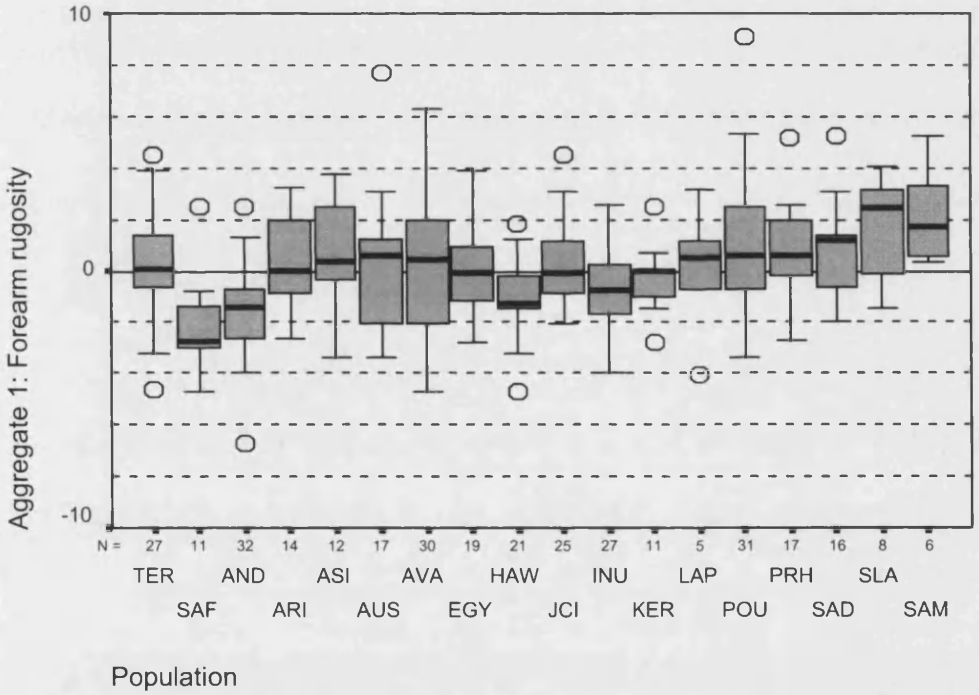
Population profiles

Boxplots of aggregated z-scores for postcranial MSMs are presented below (Figures 4.6 - 4.9), following the loadings on each of the principal component axes in the above analysis. Biologically relevant aggregation of scores for related muscle markings has been shown to be an appropriate technique to reduce error variance and improve the reliability of results (Weiss, 2001, 2003a). Z-scores are calculated for each of the variables, and summed according to the findings of the principal components analysis. Individuals with missing data for calculating the aggregated score are excluded. This method increases the sample size available for the plots, since principal components analysis removes cases with any missing data entirely, whereas some of these can be included when calculating aggregated z-scores. The body of each boxplot represents 50% of the variance, and the tails fall at the limit of variance, excepting outliers.

Forearm rugosity (Component 1) is very high among the Slavs, but only eight individuals represent this population (Figure 4.7). These belong to the hunt/herd category, which is associated with high forearm rugosity. Other populations with higher than average forearm rugosity include the Sadlermuit and South Americans. The Sadlermuit are from cold climates, also associated with high forearm rugosity. Their close relatives, the Inuit, do not show high forearm rugosity, and this difference may be due to localised differences in behaviour patterns or genetic heritage. The Hawikuh, Small African and Andaman groups have low forearm rugosity. The

Hawikuh are classified here as cultivate/hunt people, while the Andaman are classified as hunt/fish people, and both are from hot climates. Hot climates are associated with low rugosity levels generally, and cultivate/hunt lifestyles are associated with low forearm rugosity. The hunt/fish lifestyle is not associated with extremes of forearm rugosity, but the effect of hot climate alone is evidently sufficient to produce the low z-score for the Andamanese population.

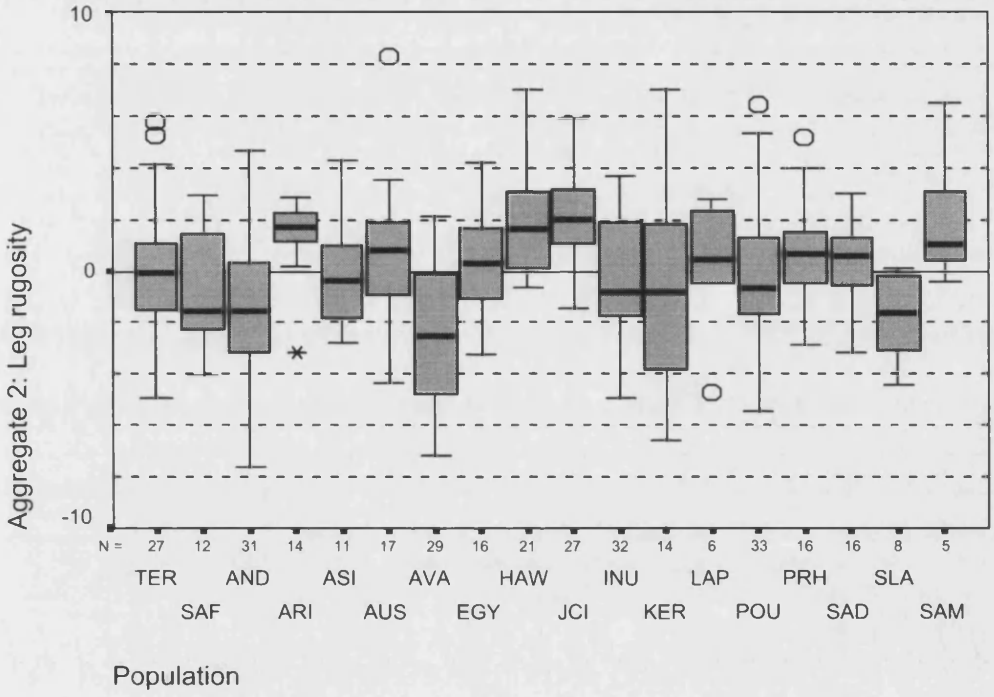
Figure 4.7: Boxplot of Aggregate Score 1: Forearm rugosity, by population



The Arikara, Hawikuh and Jersey County populations are particularly high on leg rugosity (Figure 4.8), and the Small African, Andaman, Avar and Slavic groups are low. The differences between cultivate/hunt (ARI, HAW, JCI) and hunt/herd (AVA, SLA) populations described above, explains much of these findings. However, the

association of hot climates and low rugosity must explain the findings for the Small African and Andamanese groups.

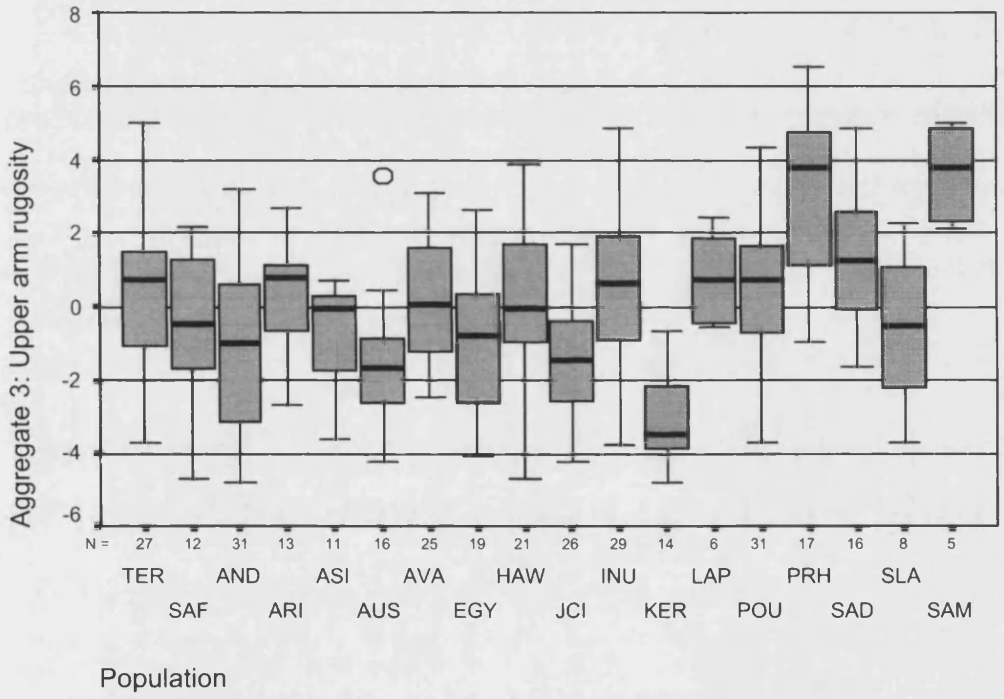
Figure 4.8: Boxplot of Aggregate Score 2: Leg rugosity, by population



The Prince Rupert Harbour and South American groups show very high upper arm and shoulder rugosity, while the Kerma fall particularly low on this aggregated score (Figure 4.9). This region of the body is hard to interpret clearly, but the Prince Rupert Harbour populations are reported elsewhere to have very rugged humeri (Weiss, 2001, 2003), as a result of their strenuous marine rowing. Other marine mobile populations, such as the Andaman, Inuit and Sadlermuit do not, however, show high scores here. The Prince Rupert Harbour population experience a temperate climate, which is associated with high general rugosity. Several of the South American individuals in this small group are also from temperate coastal populations in Chile

and Argentina. The Kerma are classified as agriculturalists from a hot climate, both of which are categories associated with medium to low rugosity. However, the other agricultural populations are not especially low on this aggregate score, so the low position of the Kerma must be due to some activity pattern specific to them.

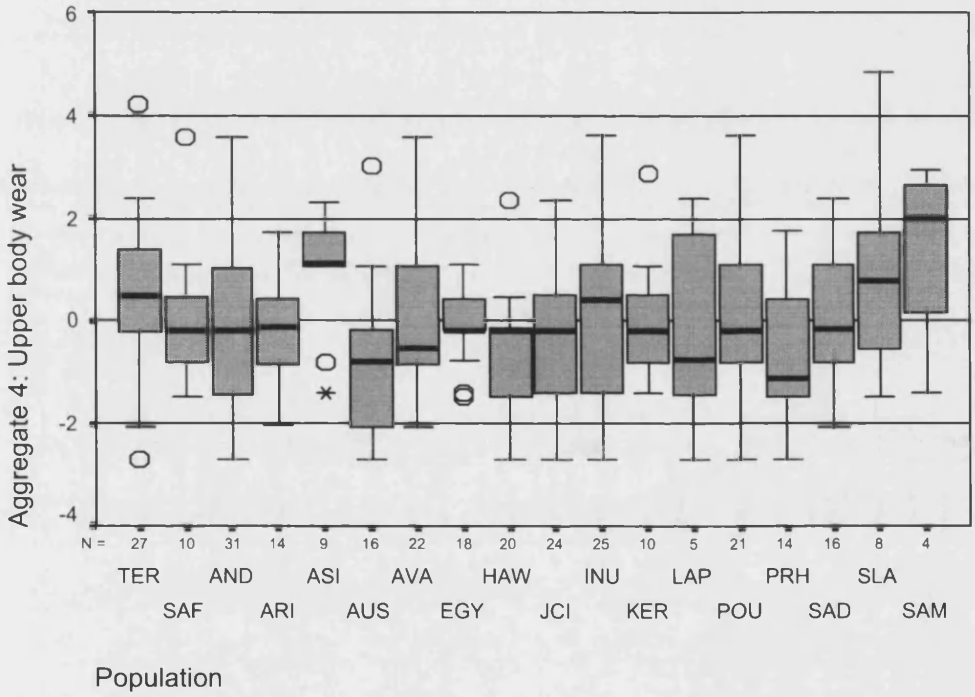
Figure 4.9: Boxplot of Aggregate Score 3: Upper arm and shoulder rugosity, by population



The Asian and South American scores for upper body wear are particularly high, but both groups are small collections of individuals of heterogeneous origin (Figure 4.10). The Asian group is dominated by the presence of Japanese males from a canning factory, which may have required hard and repetitive labour involving the arms. The explanation for the South American position on this aggregated score may be the presence of coastal rowers described above. The Kerma score low on upper

body wear, as they do for upper arm and shoulder rugosity. The individuals representing this population must have habitual activities that do not overly stress the humerus and clavicle. This was a stratified society, so a prevalence of craftspeople or clerks rather than agricultural labourers might produce this effect. The exact activity patterns must remain unknown.

Figure 4.10: Boxplot of Aggregate Score 4: Upper body wear, by population



Resulting from this study of postcranial rugosity, eight variables will be carried into Chapter 7 for use in Discriminant Function Analysis. The eight variables selected are the scores for the ulna supinator and brachialis attachments, the femur gluteal and linea aspera, the tibial tuberosity, the humerus deltoid and bicuspid groove, and the score for wear at the radial head. These are the eight most discriminatory variables, loading most strongly on the principal components, and showing interesting patterns

by population in the earlier analyses. The four aggregated scores will also be utilised in analyses where scaled data are required for comparison with the metric data.

Chapter 5 : Cranial Metric Results

Cranial variation is well understood, and has been explored in depth by other researchers (Franciscus and Long, 1991, Beals et al., 1984, Hanihara, 1997, 2000, Lahr, 1994, 1996, Howells, 1973). The inclusion of such data in this study is for comparison with the postcranial data types, in order to establish whether cranial and postcranial data distinguish between populations in the same ways. Metric data are investigated here with the aim of determining the relative importance of influences such as age, sex, climate, lifestyle and continent on cranio-facial size and robusticity.

Multi-way ANOVA with interactions are used on the data set, once individuals of unknown age and sex have been removed. This is accompanied by the characterisation of each of the major populations in terms of size and robusticity. The data are then analysed through principal components analysis in order to determine the variables that are most diagnostic of cranial variation and which can be used in discriminant function analysis. All variables are normally distributed.

The five categories used (age, sex, climate, lifestyle, continent) are the same as used for the postcrania, and there are reasons to expect all five to be significant. Age and sex affect body size and determine socially appropriate activity patterns in many cultures. Cranial morphology has been linked to masticatory stress (Hylander, 1977) and thus can be linked to diet and subsistence ecology, which are subsumed into the lifestyle category. Beals et al. (1984) demonstrated the influence of thermal

environment on head shape and volume, so climatic effects may be significant. Continent may also be expected to play a significant role, as genetic heritage may produce characteristic traits that distinguish ethnic groups.

Size

Absolute cranial and facial sizes typical for the populations in this data set can be determined from the basic cranial dimensions (Table 5.1). There are, however, several different qualities of size that are relevant when discussing craniofacial robusticity and diversity. Facial size is assessed at several points; mid-facial height (NPH), breadth across the forehead (XFB) and zygomatic bones (ZYB), orbit height and breadth (OBH, OBB), and nasal height and breadth (NLH, NLB). Measurements of cranial height (BBH), width (XPB) and length (GOL) are used to calculate cranial module.

The populations with the highest mean cranial length from glabella to opisthocranion are the Slavic, Poundbury, Prince Rupert Harbour, South American and Sadlermuit groups (Table 5.1). These all have mean lengths over 184 mm. The 75th percentile for this measurement across the whole sample is 186 mm, and only the Slavic and Poundbury means are over this value. The populations with the highest mean cranial breadth, as measured across the parietal bones at their widest (XPB), are the Prince Rupert Harbour, Poundbury, Lapp and Asian populations. Their means fall over 140 mm, which is the 75th percentile for the whole data set. Populations with high mean cranial height (BBH) are the Jersey County, Sadlermuit, Egyptian and Asian groups,

with means over 135 mm (Table 5.1). The 75th percentile for this variable is at 136.7 mm.

The smallest mean cranial lengths are found in the Andaman, Hawikuh and Lapp populations. All of these have means under 173 mm, compared with the 25th percentile of 176 mm. The populations with low mean cranial heights are the Small Africans, Andamanese and Lapps, whose means fall under 126 mm, compared with the 25th percentile value of 127 mm. The Small African and Hawikuh groups have mean cranial widths under 130.2 mm, compared with the 25th percentile of 132 mm.

The Poundbury and Prince Rupert Harbour populations therefore have both long and wide crania, while the Asian group has wide and high crania. The Small African group has narrow and low crania, while the Andamanese and Lapps have short and low crania. The Hawikuh have short and narrow crania. These patterns are clear in bivariate plots, as populations show tendency to group together (Figures 5.1 and 5.2).

Table 5.1 : Descriptive statistics for basic cranial dimensions, by population

	GOL		XPB		BBH		XFB		ZYB	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TER	180.62	6.79	134.93	4.28	128.28	4.37	115.09	5.32	130.35	6.93
SAF	176.00	7.07	129.00	4.24	118.25	10.96	111.50	.71	122.00	5.66
AND	162.55	5.23	132.21	4.70	125.88	4.70	106.82	6.01	120.05	5.64
ARI	175.93	4.10	136.82	3.55	130.37	6.04	115.50	2.72	136.81	5.58
ASI	179.73	9.24	141.68	6.04	135.32	5.90	119.82	5.19	133.05	6.53
AUS	178.86	8.81	133.38	9.62	132.64	6.59	111.64	5.13	130.71	6.88
AVA	181.40	7.85	135.60	5.55	129.50	7.13	114.54	6.43	127.00	6.89
EGY	181.86	8.03	137.74	3.96	135.00	6.44	114.24	5.23	125.56	5.22
HAW	168.69	7.00	130.19	4.88	131.03	4.92	111.40	3.35	131.24	5.78
JCI	176.25	7.82	135.06	4.60	140.41	5.92	113.68	5.34	131.94	8.36
INU	179.54	7.50	131.31	4.65	131.25	5.26	109.93	5.71	134.62	7.31
KER	183.57	6.43	133.32	5.74	132.67	4.44	112.75	5.39	124.54	8.03
LAP	172.25	3.31	140.83	2.04	123.42	7.61	117.67	3.82	126.75	4.98
POU	186.14	6.71	141.54	6.69	130.93	5.47	122.91	12.38	131.18	6.51
PRH	184.35	7.95	145.06	6.18	133.71	7.59	120.67	8.10	144.39	8.32
SAD	184.41	6.30	134.94	4.71	135.79	5.51	111.97	6.30	137.70	5.95
SLA	188.13	7.90	139.33	2.80	133.14	5.61	120.56	5.13	128.25	6.45
SAM	184.50	6.68	139.13	3.56	134.63	4.84	115.38	5.40	140.00	6.57

	NPH		NLH		OBH		OBB		NLB	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TER	70.17	3.96	51.70	3.40	36.37	2.40	40.70	2.52	26.29	2.02
SAF	55.95	1.77	42.90	.42	31.05	1.91	39.85	.49	25.95	.49
AND	58.58	3.04	45.30	2.41	32.74	1.01	37.60	1.38	23.00	1.30
ARI	69.93	4.18	53.56	3.43	35.10	2.27	40.16	1.30	25.74	1.97
ASI	69.74	4.54	53.23	3.61	35.20	1.83	39.75	1.38	25.72	2.05
AUS	65.49	5.17	51.52	3.90	35.04	2.17	41.11	2.05	25.71	1.87
AVA	62.71	6.21	50.47	3.31	33.23	1.87	38.77	1.97	24.58	2.21
EGY	68.45	5.42	51.49	3.37	34.01	2.07	39.50	2.04	25.32	1.92
HAW	67.00	4.55	49.57	2.60	35.03	1.99	38.89	1.85	24.97	1.55
JCI	70.55	5.38	52.53	3.77	35.28	2.29	40.21	2.08	25.32	1.45
INU	67.06	5.13	52.06	3.66	36.03	2.04	41.29	1.75	22.45	1.87
KER	65.03	3.08	48.93	2.54	32.63	1.99	39.92	1.66	25.21	1.84
LAP	63.25	5.20	48.93	3.48	33.88	3.71	39.18	1.27	22.42	2.01
POU	66.35	5.51	51.89	4.09	34.35	2.11	40.84	1.67	23.55	1.94
PRH	69.91	4.76	52.13	3.05	35.69	1.93	42.41	2.09	24.53	2.34
SAD	70.97	5.30	53.59	2.84	37.17	1.22	41.76	1.61	22.80	2.07
SLA	68.26	3.85	49.33	1.34	33.40	1.61	38.68	2.10	24.19	2.46
SAM	71.75	5.82	51.75	3.85	37.38	2.97	42.50	1.77	24.00	1.41

Figure 5.1: Cranial length against cranial breadth, by population

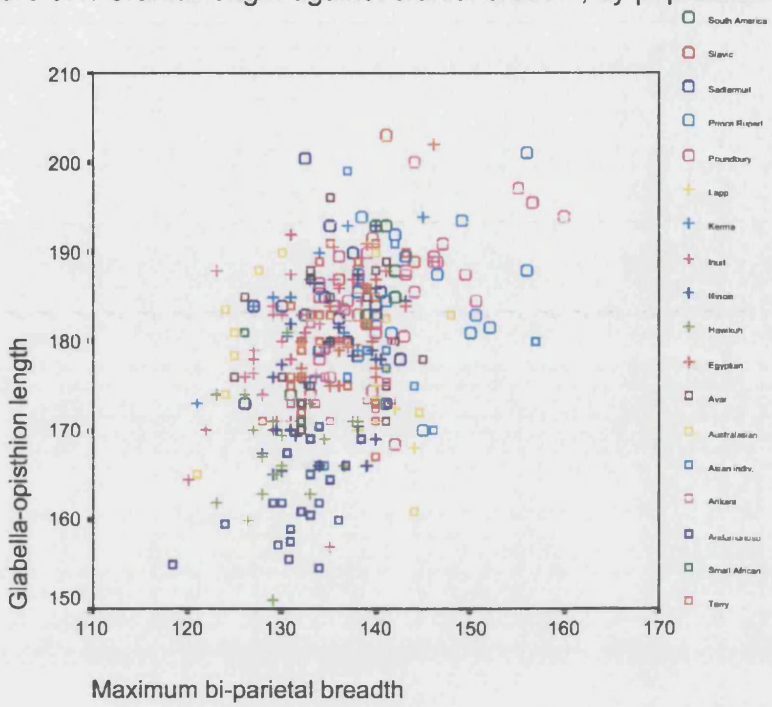
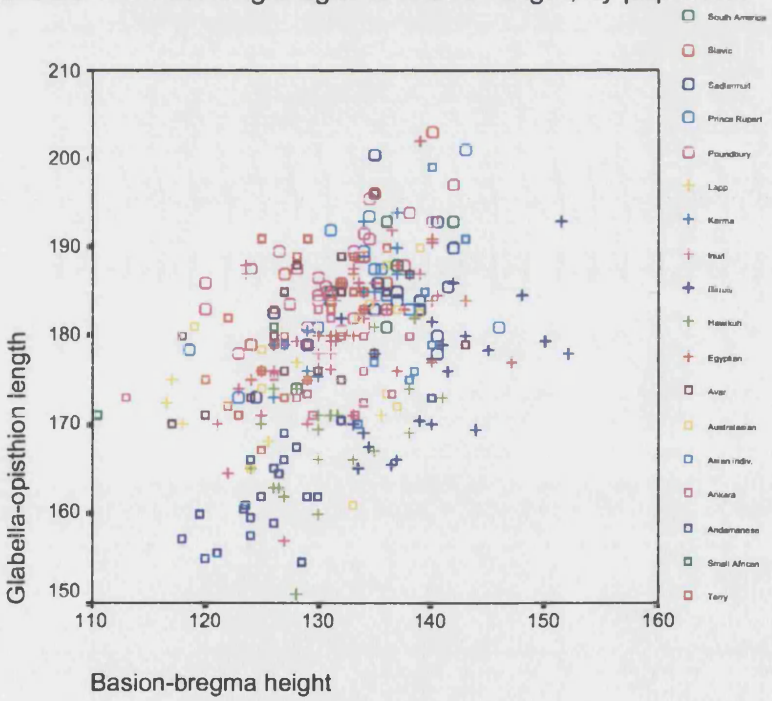


Figure 5.2 : Cranial length against cranial height, by population



These variations in cranial length, breadth and height can be used in an assessment of cranial size through cranial module. A one-way analysis of variance (ANOVA) finds greater between group than within group variance for all categories except age (Table 5.2). However, using multi-way ANOVA with interactions, only sex is shown to have a significant effect on cranial module, when all other categories are held constant (Table 5.3). There are no significant interactions between the categories, so variance in each category is random with respect to variance in the other categories.

Table 5.2 : Results of one-way ANOVA for cranial module

	Age		Sex		Climate		Lifestyle		Continent	
Index	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**
Cranial Module	2.370	.096	85.622	.000**	4.057	.003**	17.545	.000**	4.057	.003**

* = p < .05, ** = p < .01

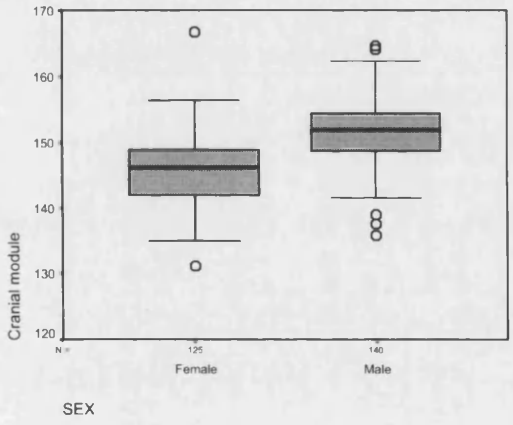
Table 5.3 : Results of five-way ANOVA for cranial module

Category excluded	SS	df	F	sig.
none	2974.815	191		
age	3709.541	230	1.036	**ns**
sex	5126.64	220	1.496	**0.01**
climate	3852.12	214	1.156	**ns**
lifestyle	3798.393	207	1.178	**ns**
continent	3661.877	207	1.136	**ns**

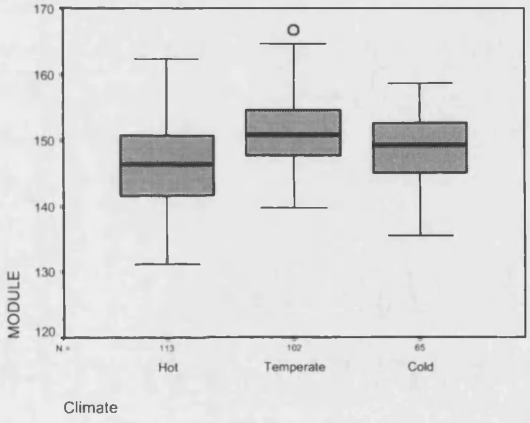
Summary

Boxplots of cranial module demonstrate how sub-categories differ, and shed light on how the population profiles are produced (Figures 5.3 a-d). They also show great overlap of mean values between the sub-categories, which may explain why the five-way ANOVA shows no significant results by any category except sex.

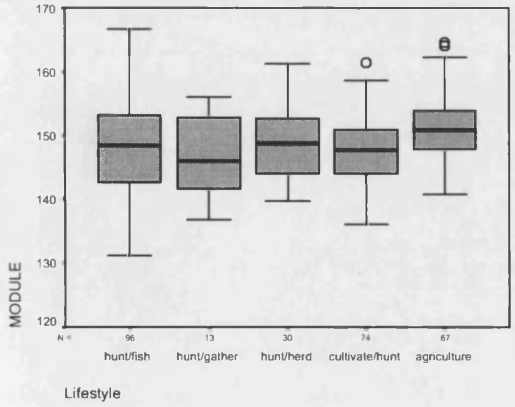
Figure 5.3 : Boxplots of cranial module by a. sex, b. climate, c. lifestyle and d. continent



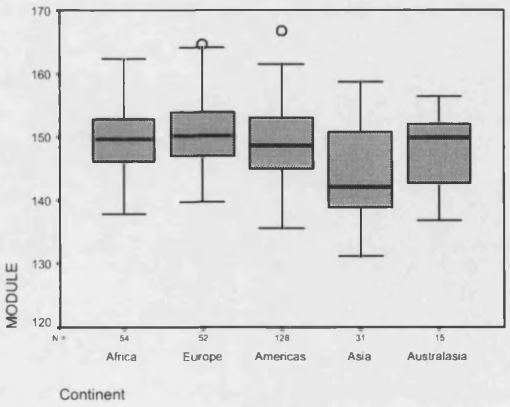
a.



b.



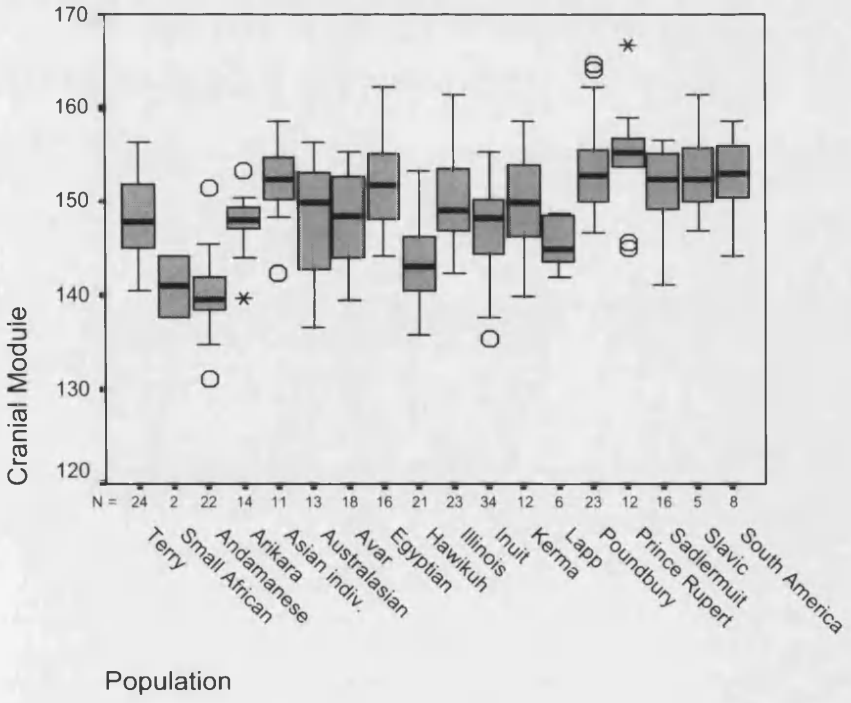
c.



d.

High cranial modules tend to be found among males of temperate climates. Low cranial modules are found in Asia. By lifestyle, there is little variation between categories. The large Andamanese sample have diminutive stature and small cranial measurements, and may well drive the low cranial module value for Asia, although the rest of the Asian individuals have large heads. The populations that can be considered to have small heads are those with means less than 144, the 25th percentile of the whole group. These are the Small African, Andaman and Hawikuh groups. The populations with large heads are the Asian, Poundbury, Prince Rupert Harbour, Slavic, Sadlermiut and South American groups. These have means over 153, the 75th percentile of the whole data set. This provides a useful comparison to refer to in subsequent sections (Figure 5.4).

Figure 5.4: Boxplot of cranial module by major population



Robusticity

The craniofacial features assessed in this study are scaled by cranial module, to produce indices comparable to those in the analysis of postcranial metric data. They derive from direct measurements of facial height and breadth at four locations, the forehead (frontal) and midface (zygomatic) breadth and the midface (nasion-prosthion) and malar heights. Like postcranial robusticity indices, they are shape indices, investigating how large, broad or tall a facial structure is for the size of the head. These variables are scaled directly using cranial module, and the formulae are listed in Chapter 2.

Facial projection (Gnathic Index) is one of the craniofacial features that Lahr (1996) relates to robusticity, so it is also included, as is the Cranial Index. The Cranial Index is reported by Beals and colleagues (1984) to be associated with climate due to thermoregulatory advantage of globular cranial form in cool climates. These authors also report association between climate and cranial capacity, indirectly for the same thermoregulatory reason (Beals et al., 1984). These assertions can also be tested with this data set. The formulae for the four robusticity indices and two shape indices are listed in Chapter 2, and descriptive statistics are presented below (Table 5.4).

Table 5.4: Descriptive statistics for craniofacial robusticity

		Cranial Module			Gnathic Index			Zygomatic Breadth Index			Nasal Height Index			Malar Height Index			Frontal Breadth Index			Cranial Index		
		Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
Sex	*Female*	145.59	5.34	124	97.75	4.78	116	.87	.04	118	.44	.03	116	.24	.03	118	.77	.03	124	234.53	19.21	137
	Male	151.46	4.90	137	97.06	4.68	126	.89	.04	130	.46	.04	123	.25	.03	129	.77	.03	135	251.21	18.15	149
Age	*Under 30*	147.83	5.99	121	98.34	4.87	118	.88	.04	117	.45	.03	114	.24	.03	117	.77	.03	120	76.24	4.24	133
	30-50	149.47	5.99	106	96.97	4.34	95	.89	.05	99	.45	.04	96	.24	.03	98	.77	.03	105	76.08	4.04	116
	Over 50	149.16	4.87	34	94.90	4.40	29	.88	.04	32	.46	.03	29	.24	.03	32	.76	.04	34	74.75	3.96	37
Lifestyle	*HG*	147.78	6.70	85	97.95	4.61	83	.90	.04	84	.45	.03	82	.26	.03	84	.75	.03	85	75.75	4.88	90
	HF	146.52	6.74	11	99.40	4.82	10	.88	.03	11	.43	.03	10	.25	.02	11	.77	.02	11	76.47	6.83	11
	HH	148.32	4.93	28	96.11	4.71	24	.86	.04	25	.43	.04	23	.22	.03	23	.77	.04	26	76.15	4.55	30
	CH	147.99	5.38	72	96.72	3.51	69	.89	.04	71	.46	.03	69	.24	.02	71	.77	.03	72	76.55	3.62	76
	AG	151.10	4.91	65	97.56	5.96	56	.86	.04	57	.46	.03	55	.23	.03	58	.78	.03	65	75.59	2.93	79
Climate	*Hot*	146.53	6.12	106	98.74	5.37	101	.87	.04	106	.45	.03	102	.24	.03	103	.77	.03	106	76.31	4.44	111
	Temp.	151.11	5.25	99	96.46	4.10	85	.88	.05	86	.45	.04	81	.23	.03	88	.77	.03	97	76.55	3.59	119
	Cold	148.41	4.89	56	96.37	3.76	56	.91	.03	56	.46	.03	56	.26	.02	56	.75	.04	56	74.15	4.16	56
Continent	*Africa*	149.44	4.97	53	98.71	5.70	50	.85	.04	53	.46	.03	50	.24	.03	50	.77	.02	53	74.52	2.90	58
	Europe	150.45	5.37	49	95.10	4.55	37	.86	.04	38	.43	.04	35	.22	.02	39	.79	.04	47	76.11	3.84	62
	America	148.63	5.60	119	96.85	3.75	116	.91	.03	118	.46	.03	115	.25	.03	118	.76	.03	119	75.86	3.98	126
	Asia	144.16	7.78	25	98.88	3.65	25	.85	.03	24	.43	.03	25	.23	.03	25	.76	.03	25	79.71	3.65	25
	Austral.	147.92	5.97	15	100.56	6.81	14	.88	.03	15	.45	.02	14	.26	.02	15	.76	.03	15	76.02	7.22	15

Using one-way ANOVA, the size-corrected cranial robusticity indices show some significant differences between sub-categories (Table 5.5). All six indices show significant differences between lifestyle and continent categories, and all but facial height index show significant differences between climate categories. Only gnathic index is significantly different between age groups, and only the zygomatic breadth, facial and malar height and cranial shape indices differ between sexes.

Table 5.5 : Results of one-way ANOVA for cranial robusticity

	Age		Sex		Climate		Lifestyle		Continent	
Index	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**
Gnathic	6.488	.002**	1.080	.300	6.977	.001**	2.517	.042*	6.272	.000**
Zygomatic breadth	.880	.416	20.879	.000**	18.474	.000**	12.062	.000**	35.598	.000**
Facial height	1.304	.273	10.519	.001**	1.572	.210	6.509	.000**	15.307	.000**
Malar height	.899	.408	7.231	.008**	23.689	.000**	13.499	.000**	8.313	.000**
Forehead breadth	1.614	.201	.004	.948	10.286	.000**	9.669	.000**	7.630	.000**
Cranial shape	1.130	.325	54.867	.000**	27.542	.000**	10.981	.000**	12.613	.000**

* = $p < .05$, ** = $p < .01$

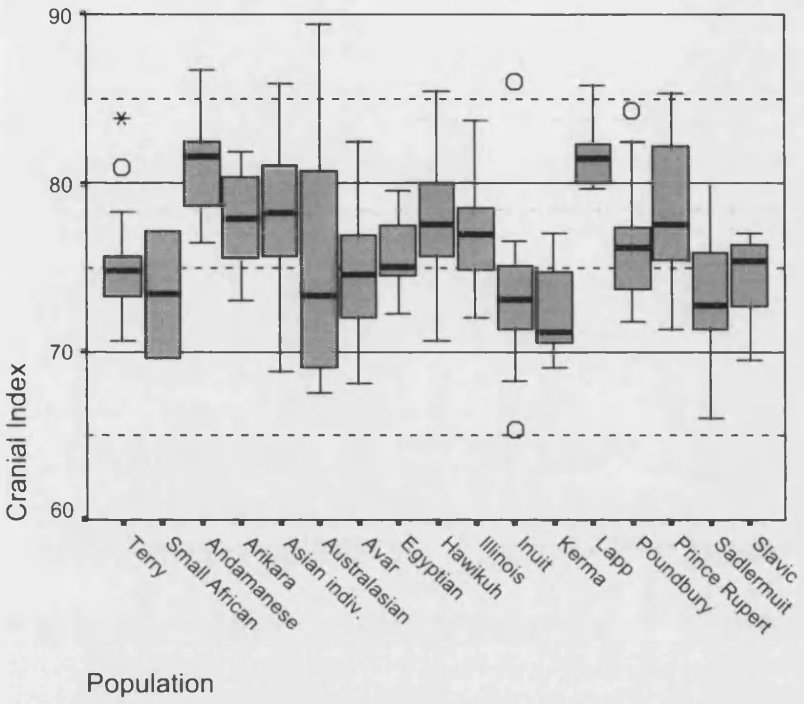
Referring to the descriptive statistics, (Table 5.4), prognathism (gnathic index) decreases with age, and females have narrower zygomatics and shorter midface and malar regions than males, even once scaled by cranial module. The cranial index is smaller among females than males as well, indicating that female crania are relatively long and narrow compared to male crania.

Hot climates are associated with larger gnathic indices, but the cold climate individuals stand out as having the broadest zygomatic regions, the tallest malar regions, the narrowest foreheads and relatively long, narrow skulls. The hunt/fish people stand out as being the most prognathic, while the mean zygomatic breadth is

largest amongst hunter/gatherers. The facial height indices differ by lifestyle; for the facial height index, both hunt/herd and hunt/gather people tend to score low, but for the malar height index, hunt/herd people score low, but hunt/gather and hunt/fish groups tend to score high. Forehead breadth tends to be wide among the agriculturalists, and narrow among the hunt/fish group. Cranial index (cranial shape) may well be significantly different in variance between the lifestyle categories, but the mean values are close together.

The Australian continent has the highest mean gnathic index, which supports established research. The American continent is notable for having the broadest zygomatic and frontal regions, but the European continent have the largest cranial module. Cranial index distinguishes the Asian group as having relatively wide, short heads, and the African group as having relatively long, narrow heads. The population profiles below show how these trends translate from ethnic differences within the dataset.

Figure 5.5 : Boxplot of cranial index by major population

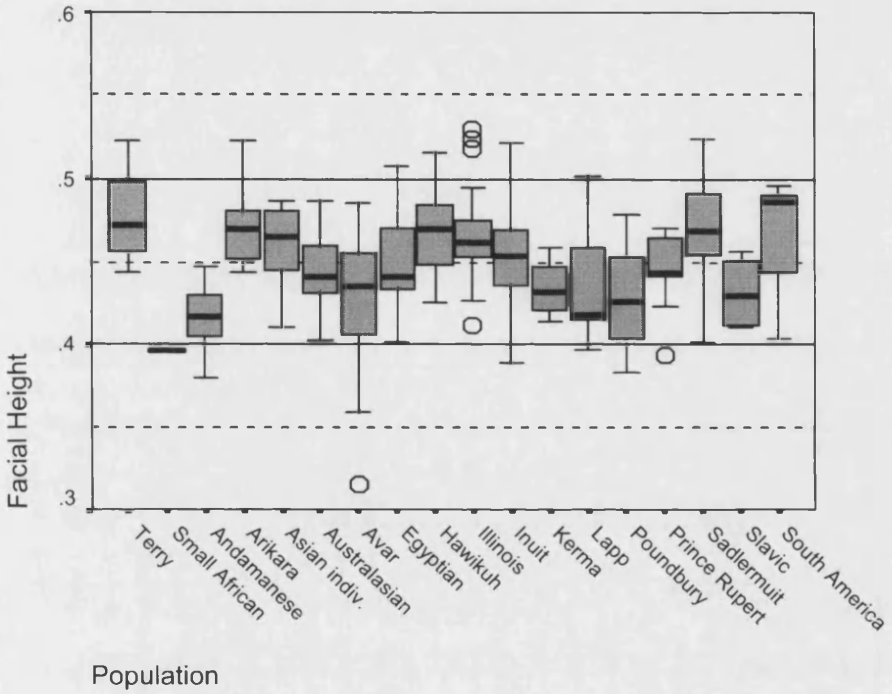


The population profile for cranial index is not at all similar to that of cranial module (Figures 5.4 and 5.5). The populations with low means are the Kerma and Sadlermiut, which fall below 73.2, the 25th percentile for the whole data set. The Inuit and Australasians also have means close to this figure. The 75th percentile is 78.6, and the Lapp and Andamanese have means which fall above this, with the Asian and Arikara groups nearby. These are not grouped climatically, since populations from both hot and cold climates fall high and low on this index.

Facial height as measured from nasion to prosthion, and scaled using cranial module, also shows a different population-specific pattern to cranial size (Figure 5.6). The 25th percentile is at .43, and those populations with means lower than this can be considered to have short mid-facial regions. These are the Andaman, Lapp,

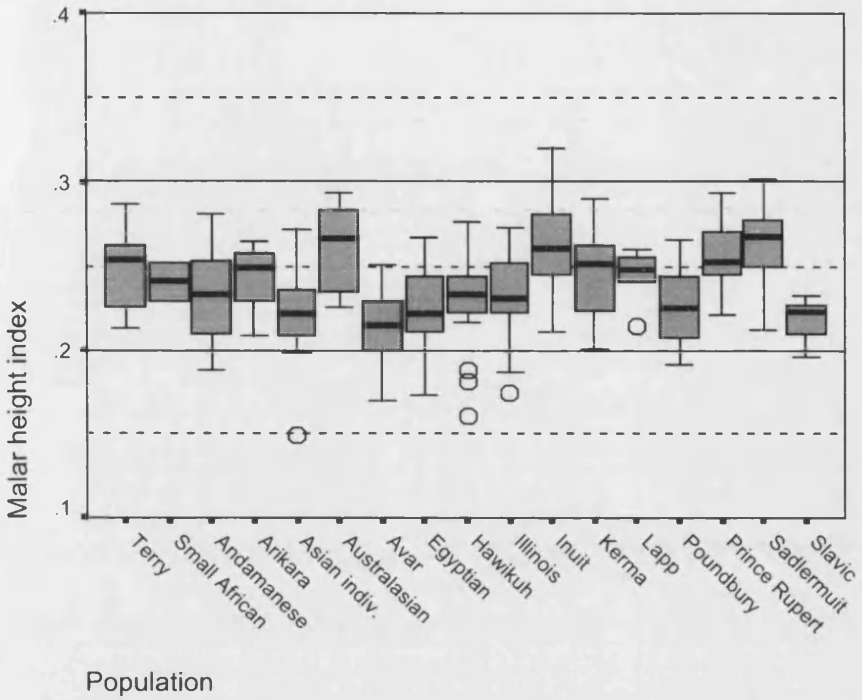
Poundbury and Slavic populations. Those with relatively tall mid-facial regions are the Terry, Arikara, Hawikuh and South American groups, where the means are above .47, the 75th percentile.

Figure 5.6: Boxplot of facial height index by major population



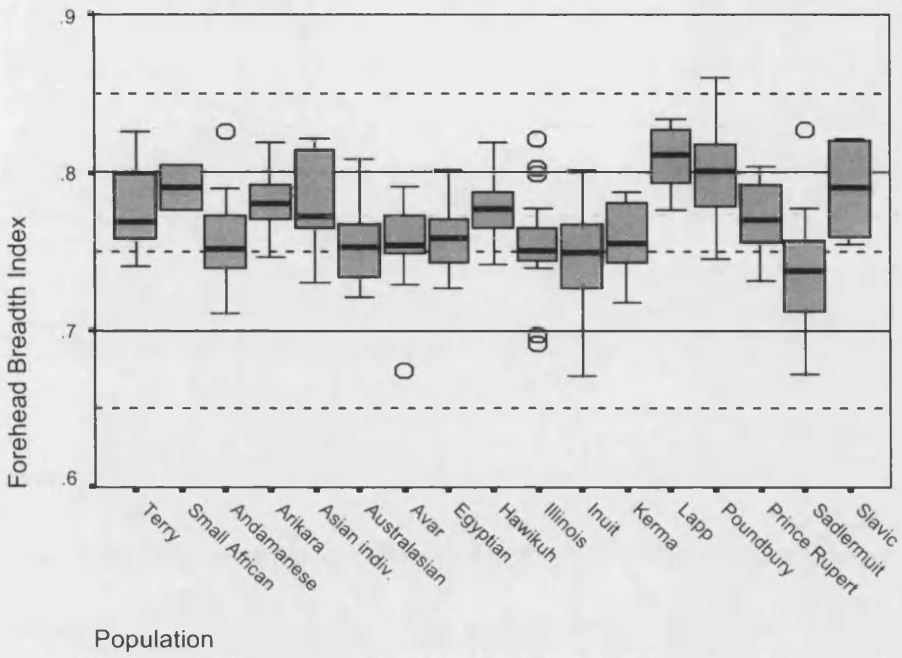
For the malar height index, the height of the malar region relative to cranial module, the population pattern is different again (Figure 5.6). The populations with short cheekbones are the Asians, Avar, Egyptians and Slavic groups, which have means under .25, compared with the 25th percentile value of .22. The 75th percentile value is .26, and the Australian, Inuit and Sadlermiut all have means that fall above this. A tall, flared malar region is a characteristic trait of Arctic American populations, and strong cheekbones are also associated with Australian populations.

Figure 5.7 : Boxplot of malar height index, by major population



The two indices of facial breadth also demonstrate different patterns to each other, and to the indices of facial height. For the index of forehead breadth, no population means fall below the 25th percentile for the whole sample (.745), but the Sadlermiut fall lowest of all the populations (Figure 5.8). They have the narrowest frontal bones relative to cranial module, but then they do have a large mean cranial module. The Small African, Lapp, Poundbury and Slavic populations all have means that fall above the 75th percentile, .786, and can be considered to have broad frontal bones.

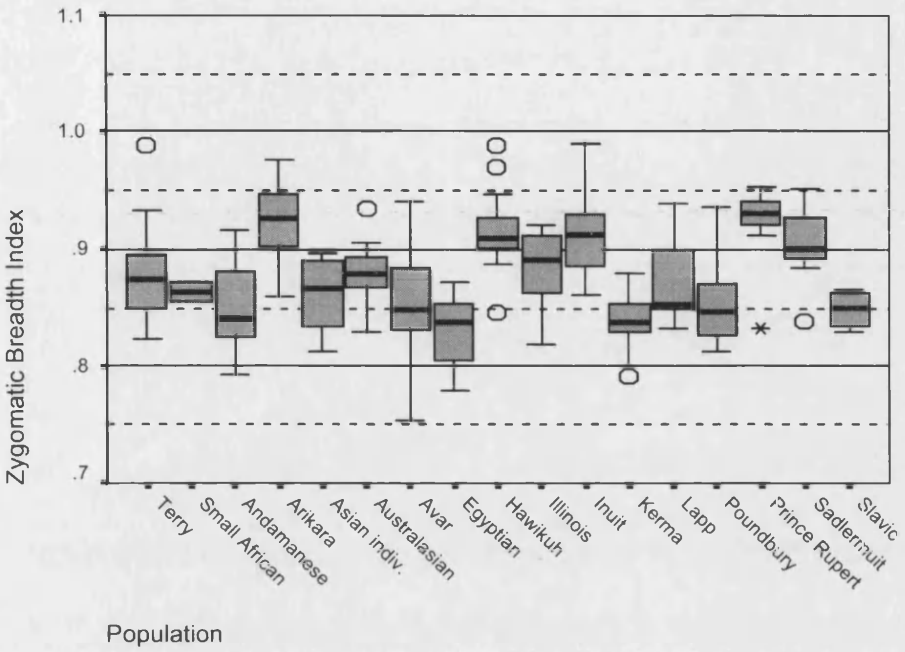
Figure 5.8: Boxplot of forehead breadth index, by major population



The Andamanese, Egyptian, Kerma, Poundbury and Slavic populations have low mean zygomatic breadth indices, under .85, when the 25th percentile falls at .846 (Figure 5.9). These are populations with narrow faces at the cheekbone level, relative to cranial module. The Andamanese have small crania, the Poundbury and Slavic groups have large crania, and the Kerma and Egyptian are intermediate, but they fall together on this index.

The high scoring populations, with mean zygomatic breadth indices over the 75th percentile (.917), are the Arikara and Prince Rupert Harbour populations. The Hawikuh, Inuit and Sadlermiut also rank high on this index, having means over .9. These are all populations from North America, where wide cheekbones are an established trait.

Figure 5.9 : Boxplot of zygomatic breadth index, by major population

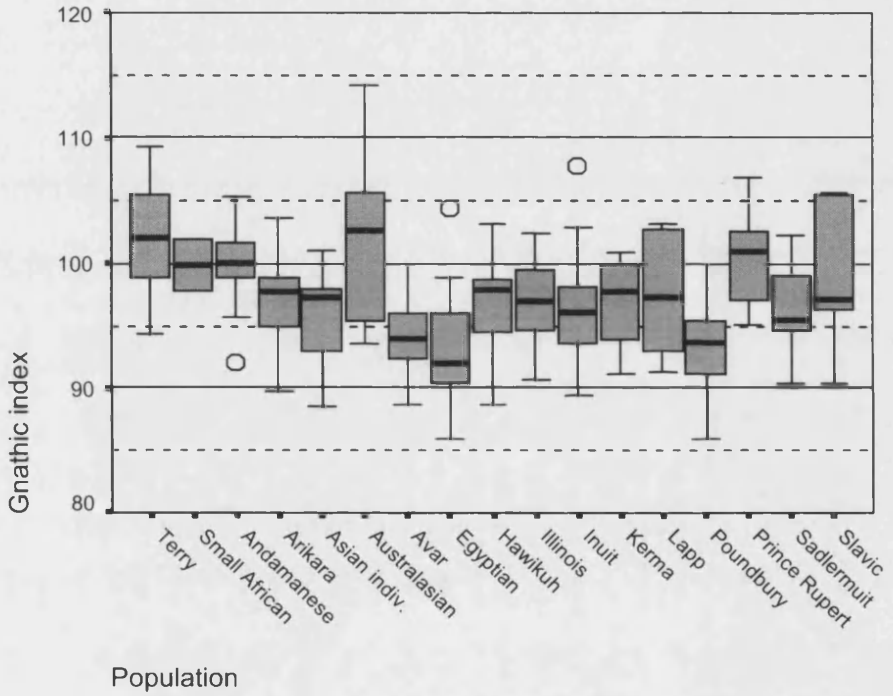


The index of facial projection is similarly informative and diverse (Figure 5.10). The populations that have low mean scores for gnathic index are the Avar, Egyptian and Poundbury collections. These have mean index scores under 95, compared with the 25th percentile value of 94.1. Other European and North African populations are not particularly low on this index.

The Terry, Small African, Andamanese, Australasian and Prince Rupert Harbour groups fall on or above a mean of 100 for the gnathic index. This is the 75th percentile value, and indicates that these groups have relatively protruding alveolar regions. This position for the populations of African or Australasian origin is expected, since relative prognathism is a characteristic trait of populations from these regions. However, the Prince Rupert Harbour population consists of ethnic

Canadians, and prognathism is not usually considered to be a characteristic trait of this group. Since the gnathic index is basion-prosthion length scaled by basion-nasion height, a low measurement on this could produce a high gnathic index as well as a large basion-prosthion length.

Figure 5.10: Boxplot of gnathic index by major population



Five-way ANOVA

Using multi-way ANOVA, none of the five categories show significant influence on cranial shape, facial robusticity, or facial projection, when other categories are held constant (Table 5.6). The lack of a significant result for climate fails to support the findings of Beals et al. (1983, 1984).

There are some significant interactions between categories for the gnathic, forehead breadth and cranial shape indices, but not other indices (Table 5.7). Age is involved in interactions with sex, lifestyle and continent, and continent and climate are also involved in significant interactions with each other.

Table 5.6 : Results of five-way ANOVA on facial robusticity

Cranial Index					**Gnathic Index**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	2572.304	216			none	3045.246	175		
age	3070.884	255	1.011	**ns**	age	4215.94	211	1.148	**ns**
sex	2903.931	247	0.987	**ns**	sex	3699.651	205	1.037	**ns**
lifestyle	2994.978	239	1.052	**ns**	lifestyle	3522.056	196	1.033	**ns**
climate	3209.995	232	1.162	**ns**	climate	3439.681	190	1.040	**ns**
continent	3149.971	232	1.140	**ns**	continent	3465.898	190	1.048	**ns**
Facial Height Index					**Malar Height Index**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	0.121	173			none	0.102	177		
age	0.168	212	1.133	**ns**	age	0.129	216	1.036	**ns**
sex	0.168	204	1.177	**ns**	sex	0.124	208	1.035	**ns**
lifestyle	0.149	194	1.098	**ns**	lifestyle	0.119	200	1.033	**ns**
climate	0.132	188	1.004	**ns**	climate	0.112	193	1.007	**ns**
continent	0.145	188	1.103	**ns**	continent	0.116	193	1.043	**ns**
Zygomatic Breadth Index					**Forehead Breadth Index**				
Category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	0.216	179			none	0.147	189		
age	0.254	218	0.966	**ns**	age	0.182	228	1.026	**ns**
sex	0.274	209	1.086	**ns**	sex	0.173	220	1.011	**ns**
lifestyle	0.241	202	0.989	**ns**	lifestyle	0.179	212	1.086	**ns**
climate	0.237	195	1.007	**ns**	climate	0.174	205	1.091	**ns**
continent	0.277	194	1.183	**ns**	continent	0.161	205	1.010	**ns**

Table 5.7: Summary of interaction effects on facial robusticity

Index	Significant interactions
Cranial shape index	age x sex *
Forehead breadth	age x lifestyle *
Gnathic index	age x sex * age x continent * continent x climate *

Summary

Facial indices show more diversity than postcranial indices of robusticity in terms of the profiles that different populations exhibit. This suggests that the different populations really do have different levels of robusticity in the cranio-facial skeleton, and that idiosyncratic individual differences in facial robusticity are more constrained within ethnic groups than postcranial robusticity differences. However, populations do not tend to have consistent levels of robusticity across all the indices. They may have broad, robust zygomatics, or tall midfacial regions, but low prognathism and short malars.

Describing facial differences is an important part of individual recognition, and facial differences have played a large role in racial and ethnic identification, resulting in commonly recognised 'types' for ethnic groups. For example, The populations of the Americas tend to have broad, flat faces, but the Canadian groups also tend to have tall malars. The European populations tend to have broad foreheads, and narrow cheekbones, but they vary in facial height.

These typical facial types may arise simply from genetic drift within isolated populations, or may have functional relationships with facial musculature. No single category in this study is sufficient to explain variation in any of the facial robusticity or projection indices, but there may be other subtleties of face functional morphology that have not been addressed here. The significant interactions between age and other categories suggest that age changes in cranial shape and facial robusticity through life are influenced by other factors. The preliminary conclusion here must be that human facial robusticity, as measured in these indices, is a complex phenomena that cannot be reduced to simple explanations.

Principal Components Analysis

Principal components analysis (PCA) reduces the variation in a data set to a smaller number of significant components. This allows meaningful information to be gained from the large numbers of related metric variables taken on the crania in this study. Rotation following the Varimax method optimises the significance of the components while keeping the axes orthogonal. The PCA scores are presented in bivariate scatters as individual scores labelled by region. The regional categorisation is used in order to reduce the complexity of the graphs, and is listed in full above. Descriptive statistics are presented by the major populations, as in Chapters 3 and 4.

The first run of the analysis used all 47 available variables, and many individuals were omitted due to having missing data. No missing data have been filled for the crania, since to do so would mean making assumptions about the internal structure of the data set, which could influence the results of the analysis. The sample size for PCA 1 is 198 individuals, representing all the major populations in the data set. The rotation converged in 43 iterations, which is unsurprising, given the very large number of variables included.

The variables that load strongly and exclusively on each component fall into distinct categories, describing different aspects of cranio-facial shape and size (Table 5.8). While the first component in a PCA traditionally is referred to as the size component, in the analysis of a complex form like the skull, there are many kinds of size. In this case, the first component relates to facial breadth, since variables such as bi-

zygomatic breadth, bi-jugal breadth and orbit breadth are loaded onto it. This component does not separate populations or regions strongly (Figure 5.10), although the three Canadian populations, the Terry Blacks (African Diaspora), the Polynesians and the Arikara all score highly on facial width, while the Avar, Egyptian, Kerma, Andaman and Lapp populations score low on this component (Table 5.9).

Table 5.8 : Cranial Metric PCA 1: all 47 metric variables

Component	**Loaded variables over .6**	**Interpretation of loading**	**Rotation Sums of Squared Loadings**		
			Total	% of Variance	Cumulative %
1	JUB, FMB, ZYB, EKB, OBB, AUB, XML, ZMB, WCB	Facial breadth	7.195	15.310	15.310
2	NAS, WNB, DKB, SIS	Nasal width and projection	4.249	9.041	24.351
3	BPL, PLL	Lower face projection	3.758	7.996	32.347
4	XPB, XFB, ASB	Calvaria breadth	3.174	6.754	39.101
5	PAC, PAS, PAF	Parietal shape	2.846	6.055	45.156
6	FOB, FOL	Foramen magnum size	2.765	5.882	51.038
7	OCF, OCC	Occipital shape	2.669	5.678	56.716
8	OBH, NPH, NLH	Midface height	2.249	4.785	61.500
9	OCS	Occipital chord subtense	2.155	4.585	66.085
10	MDH	Mastoid height	1.958	4.165	70.250
11	FRS	Frontal bone subtense	1.501	3.193	73.443

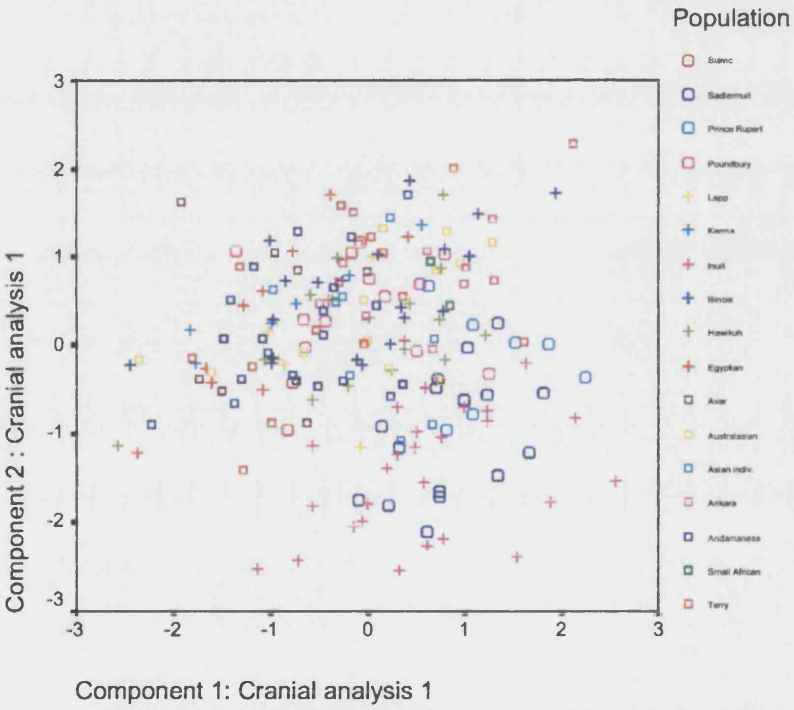
(See chapter 2 for variable codes)

Table 5.9: Population mean scores for cranial PCA 1

Compont.	1		2		3		4		5		6		7		8		9		10		11	
Popn.	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
African diaspora	-0.165	1.149	0.513	1.063	0.681	0.967	-0.076	0.862	-0.416	1.183	0.263	1.233	-1.176	1.036	0.481	0.644	0.590	0.836	-0.106	1.166	0.499	1.060
African (small)	0.750	0.150	0.704	0.348	-0.309	1.093	-0.870	0.887	-0.613	0.031	0.472	1.561	-1.074	0.779	-2.195	0.784	0.226	0.798	-0.588	1.819	1.923	0.994
Andaman	-0.692	0.683	0.134	0.712	-0.476	0.619	-0.697	0.709	-0.461	0.875	-0.553	0.627	-0.396	0.751	-0.975	0.558	-0.825	0.677	-0.090	0.788	0.013	0.949
Arikara	0.380	0.668	0.822	0.440	0.412	0.468	0.348	0.717	-0.878	0.770	-0.456	0.884	-0.013	0.692	0.843	0.894	-0.409	1.080	0.508	0.659	-0.264	0.782
Asian	0.018	0.563	0.111	0.846	-0.104	0.965	0.792	0.679	-0.034	1.102	-0.057	0.983	0.675	0.883	-0.011	1.000	-0.063	1.000	0.052	1.024	1.111	1.399
Australasia	0.016	1.086	0.413	0.673	0.540	1.149	-0.314	1.244	0.683	1.033	0.097	0.788	0.200	0.977	-0.370	0.931	-0.349	1.169	-0.121	0.552	-0.224	0.621
Avar	-1.069	0.686	0.370	0.945	-0.762	1.386	0.183	0.857	0.028	0.777	0.801	1.130	-0.273	0.410	-0.133	1.114	0.315	1.114	1.353	0.297	-0.924	0.784
Egyptian	-1.031	0.788	0.320	0.904	0.227	0.962	0.266	0.337	1.267	1.002	1.160	0.828	0.253	0.449	0.327	0.911	-0.340	1.030	-0.437	1.286	0.346	0.930
Hawikuh	-0.025	0.929	0.187	0.688	-0.568	0.966	0.024	0.778	-0.037	0.671	-1.385	0.864	-0.098	0.673	0.401	0.973	-0.195	0.863	0.722	1.034	0.290	0.872
Illinois	-0.052	0.995	0.608	0.663	0.218	0.894	-0.411	0.730	-0.159	0.688	-0.132	0.639	1.110	0.781	0.371	0.619	-0.481	0.751	0.055	0.914	-0.011	0.860
Inuit	0.588	0.866	-1.374	0.753	-0.128	1.082	-0.464	0.759	-0.042	0.679	0.313	0.734	-0.165	0.807	0.231	0.993	0.212	0.748	-0.189	0.924	-0.358	0.804
Kerma	-0.834	0.920	0.477	0.542	0.131	0.943	-0.456	0.924	1.118	1.029	0.410	0.434	0.357	0.757	-0.520	0.937	0.637	0.382	-0.356	1.140	-0.442	0.836
Lapp	-0.568	0.512	-0.075	0.775	-0.252	0.907	1.593	0.285	-0.847	0.777	-0.057	0.986	0.002	0.613	-0.816	0.523	-0.154	0.868	-0.878	0.227	-0.369	0.936
Poundbury	0.017	0.795	0.427	0.468	-0.577	0.931	1.380	0.897	0.594	1.000	0.155	0.727	-0.794	0.299	-0.285	0.787	1.113	0.704	-0.070	0.742	-0.351	0.522
Prince Rupert	1.322	0.587	-0.158	0.575	0.506	0.805	1.130	0.943	-0.356	0.688	-0.520	0.750	0.539	1.724	-0.776	0.811	0.886	1.371	-0.289	0.547	0.199	0.909
Sadlermuit	0.843	0.548	-1.007	0.703	0.217	0.782	-0.263	0.936	0.001	0.831	0.454	0.774	0.212	0.793	0.525	0.911	0.204	0.860	-0.255	1.214	0.037	1.211
Slavic	-0.463	0.393	0.216	1.055	0.276	1.685	1.208	0.689	1.371	1.133	0.810	1.180	0.327	2.058	-0.761	0.651	0.641	1.266	0.096	1.573	0.119	1.841

The second component describes the configuration of the nasal bone and its immediate neighbours, with variables relating to width between the orbits and the projection of the nasal bone. The height and breadth of the nasal aperture are not loaded here, nor do they feature strongly on any component. This variable does separate the Arctic Americas from the other populations, (Figures 5.11 and 5.12) since all but the Inuit and Sadlermiut score medium to high on this component. The two Arctic American populations have wide and flat nasal bones.

Figure 5.11 : Cranial PCA 1: Components 1 and 2 by population

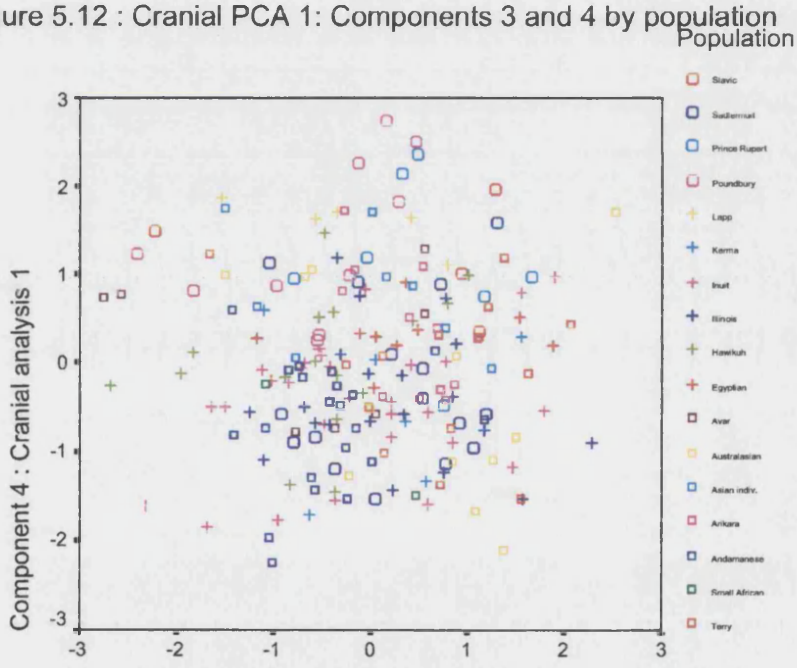


Component 3 has variables associated with lower face projection, such as palate length and basion-prosthion length, loaded strongly upon it (Table 5.9). It does not separate the populations in a scatter plot (Figure 5.12), but the populations which

score high upon this component include Prince Rupert Harbour, the Terry US Blacks, Australasia and the Arikara. The Hawikuh, Poundbury and Avar populations have shorter lower faces, and score low on this component.

Component 4 links the variables associated with calvaria breadth, the breadth across the parietal bones, the frontal bones and the bi-asterionic breadth. Again, the regions are not well separated, but the Andamans score low, although other individuals with narrow calvaria come from the Arctic Americas and Europe. The populations shown to have broad calvaria include those from Australasia, Africa, and North Africa, including the Terry US Blacks.

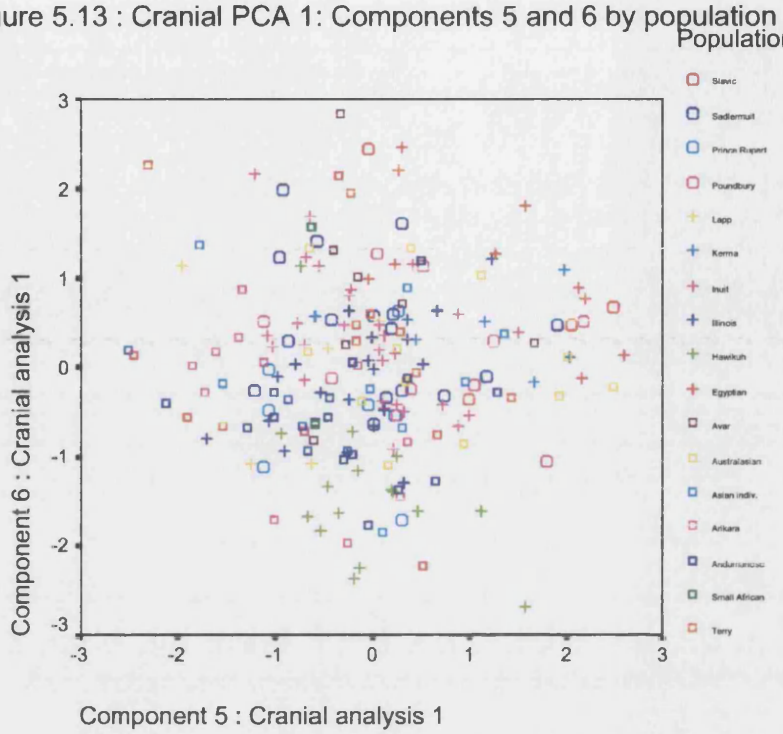
Figure 5.12 : Cranial PCA 1: Components 3 and 4 by population



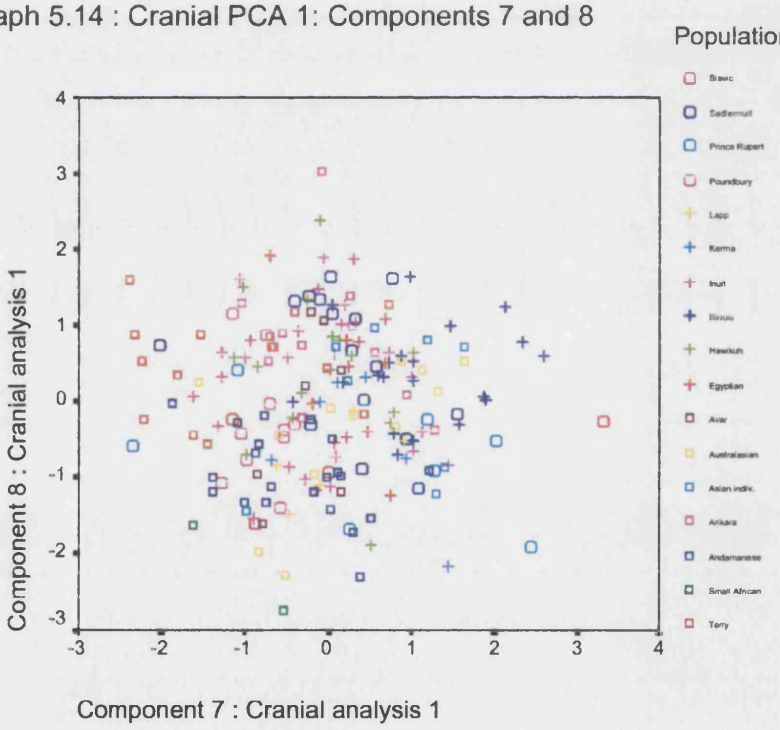
Component 5 reflects parietal bone size and curvature, and separates the populations somewhat better than components 3 or 4 (Figure 5.13). The North African groups (Kerma and Egypt) score high, as do the Australasians, whilst the Andamanese, Arikara and Jersey County, Illinois score medium to low on this component. Component 6 reflects foramen magnum shape, and pulls the Hawikuh out with their low score, implying that the foramina magna of this group are particularly small. Europe, North Africa and Arctic Americas score medium to high on this component.

Component 7 represents the shape of the occipital bone, and does not pull the regions apart on a plot (Figure 5.14). African groups show both high scores (Kerma and Giza), and low scores (Terry and others). The Avar, Asian and Prince Rupert Harbour populations also have high scores on component 7. Component 8 reflects the height of the midface region, and the Prince Rupert Harbour population fall generally lower than the other regions, which are evenly spread. The Lapp and Andaman also have a low mean score for component 8, while the Arikara have a high mean score (Table 5.8).

Figure 5.13 : Cranial PCA 1: Components 5 and 6 by population



Graph 5.14 : Cranial PCA 1: Components 7 and 8



Further components are not plotted graphically, since no separation is produced. Components 9 and 10 reflect occipital chord subtense and mastoid height respectively, although they account for very little of the variation in the data set (Table 5.7). Europeans tend to score high on mastoid size, and the Andamanese group low on occipital chord subtense. The small skulls of the Andamanese may produce an unusually high curvature in the occipital. The European mastoid is known to be large, and this result confirms previous findings.

Component 11 relates only to frontal bone subtense, and explains little variation in the data set. Populations scoring high on this include the small African and Asian groups, while the Avar score low. This is the only component where the means for Sadlermiut and Inuit are very different. Since the Sadlermiut and Inuit were measured at the same time, it is unlikely that measurement error is significant here. The slight differences noted at this level of significance must be truly indicative of population-specific traits.

Several other PCA runs were carried out, using subsets of the variables in order to ascertain the degree to which the components produced in the first principal components analysis rely on specific variables, and to increase the sample size. In each case, although the order of the components sometimes varied, the grouping of variables on each one remained stable. The second PCA presented, (Table 5.9) has a sample size of 219, and uses only the variables listed in table 5.8, that were loaded strongly and uniquely on one component. The rotation converged in ten iterations, and six components were extracted. The loadings for variables are listed (Table

5.10). The first four factors are presented graphically in Figure 5.17 to illustrate the clustering of variables on each component.

Table 5.9: Cranial PCA 2: Total variance explained and loading of components

Component	Interpretation of variable loading	Rotation Sums of Squared Loadings		
		Total	% of Variance	Cumulative %
1	Facial breadth	4.817	22.939	22.939
2	Nasal saddle morphology	2.361	11.242	34.181
3	Parietal shape	2.243	10.682	44.863
4	Calvaria breadth and occipital curve	1.838	8.753	53.616
5	Foramen magnum breadth	1.708	8.132	61.749
6	(Mastoid size)	1.407	6.701	68.450

The first component is more obviously a size component in this run, incorporating general facial breadth measurements (Table 5.10). The grouping of populations on this component matches the findings of the analysis of the distribution of means for cranial module, and the facial robusticity indices, with the Andamanese low and populations like the Poundbury, Terry and Arctic people scoring high (Figure 5.15).

Component 2 mainly separates the Arctic (Inuit and Sadlermiut) and non-Arctic people (Figure 5.14). In this principal components analysis, this component reflects nasal morphology, which is distinctive in the Arctic populations. Many individuals among the Inuit and Sadlermiut have pinched nasal saddles and narrow inter-orbital distances. Component 3 pulls the North African (Kerma and Egyptian) populations out high, with the remaining individuals falling medium to low (Figure 5.16). This

component represents the profile of the parietal bone, where the North Africans are distinctive in having long, but rounded profiles. Component 4 incorporates calvaria breadth and occipital morphology, but does not distinguish between populations, and neither do Components 5 and 6 (not shown). Each of these latter three components account for less than 10% of the variance in the data set.

Table 5.10: Rotated component matrix: Cranial metrics

Component	1	2	3	4	5	6	7	8
JUB	.878	.113	.171	.148		.199		
ZYB	.846		.275	.251		.157	.150	
FMB	.779	.236	.136	.239	.194	.113		.306
ZMB	.751					.215	.108	-.181
EKB	.747	.268		.225	.189	.114		.307
AUB	.725		.490	.232			.193	
XML	.666	-.209				.263	.150	
WCB	.654	-.269	.308	.287			.137	
OBB	.592			.406	.235			.405
MDH	.379	.160				.365	.194	-.262
WNB	-.111	.845	.127	-.141				
DKB	.114	.752		-.136	.152	.153		
NAS		.736	-.255		.105		.103	
SIS		.711	.340	.124		.143	.105	
XPB	.225	.173	.777		.102		.195	-.106
XFB	.305	.249	.734	.123	.221			
ASB	.303		.671	.125	.111	.123	.275	.221
FRS		-.245	.529		.364		-.258	.239
OBH	.283	-.126		.791			-.115	.164
NLH	.384		.189	.727		.294	.173	
NPH	.346		.131	.691	.107	.412	.188	
PAC	.208	.123	.185		.806	.195		
PAS	.108				.788	-.213		-.395
PAF			.130		.642	.238		.222
BPL	.372		.117			.801		
PLL	.280	.150		.178	.127	.781		.140
OCF	.161		.124				.836	
OCC	.135		.179	.163		.118	.761	.278
OCS	.296					.170	.358	.623

(Sorted by size; values under 0.1 not shown)

Figure 5.15 : Cranial PCA 2: Components 1 and 2 by population

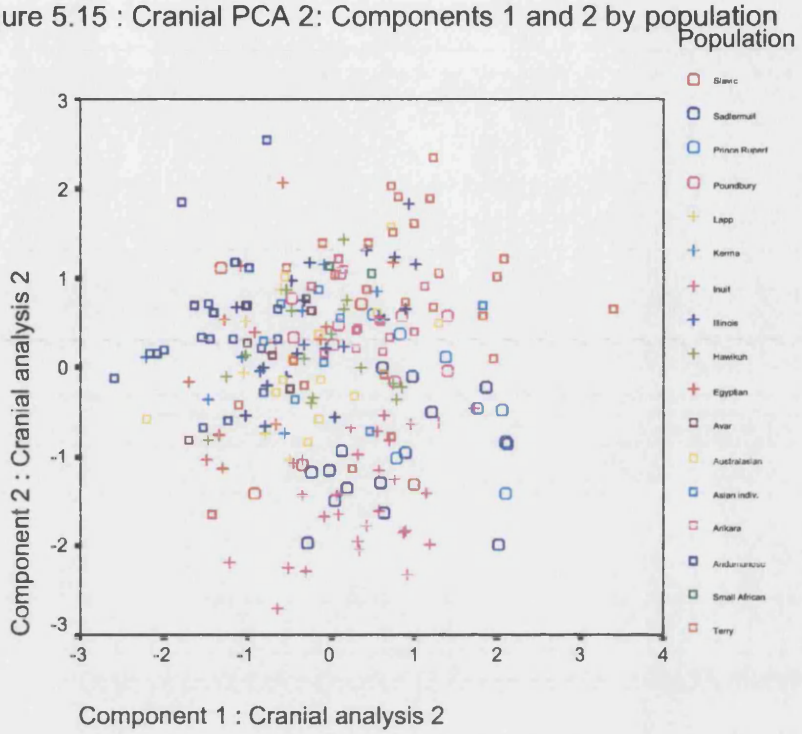


Figure 5.16 : Cranial PCA 2: Components 3 and 4 by population

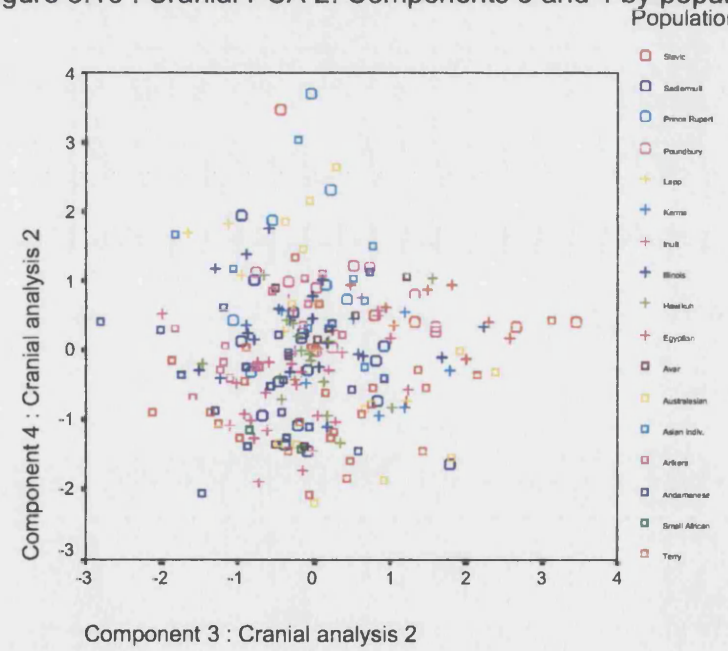
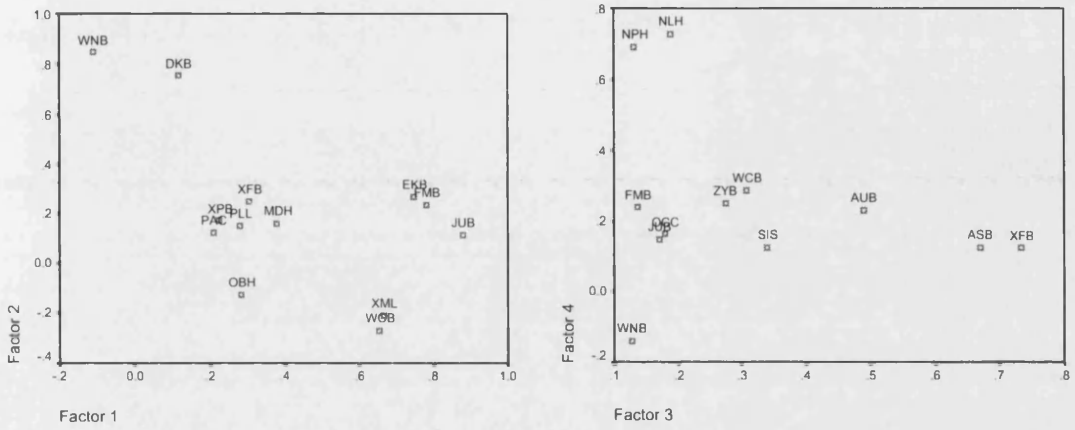


Figure 5.17 : Cranial PCA 2: a. Components 1 and 2 by variable. b. Components 3 and 4 by variable



Summary

The results of the principal components analyses match the results of the analysis using indices, with populations behaving similarly on components that approximate the indices. This shows the index approach to have value, particularly since relatively few measurements are needed. Both analyses support in general the findings of previous multivariate studies into craniofacial diversity (Howells, 1973, Stringer, 2001 Lahr, 1996). This indicates that the populations used in this study are typical of their regions and ethnic backgrounds.

No single category has been shown to have significant influence on the indices of cranial shape, facial robusticity and facial projection. Nonetheless, the populations are distinctive in their robusticity profiles, and several are well separated by the principal components analysis. This demonstrates that the categorisations used in

this analysis do not correspond to the sources of distinctive variation among populations. It is likely that genetic drift and isolation produced the craniofacial differences between populations, rather than any external influences. However, it is possible that using finer distinctions between categories such as dietary types or thermal experience might provide significant results.

The variables that will be carried over into the discriminant function analysis are the eight most diagnostic of the cranial variables in these analyses. They are limited to eight to match the number of variables from the other data types (postcranial metric, postcranial scores, cranial scores). It includes the relevant variables from the first principal components analysis, without duplicating, and thereby over-weighting, variables from the same component which measure similar regions of the craniofacial skeleton (Table 5.11). Where there is more than one option to represent a component, the variable with fewest missing values is used.

Table 5.11: Cranial metric variables used in discriminant function analysis

Howells Code (1973)	Description
ZYB	Bi-zygomatic breadth
XPB	Bi-parietal breadth
PLL	Palate length
FOB/FOL	Foramen magnum breadth/length
OCF/OCC	Occipital chord
OBH	Orbit height
DKB	Dacryon-dacryon breadth
PAC	Bregma-lambda chord

Chapter 6 : Cranial Scored Results

Introduction

Robusticity in relation to the crania has often meant what is defined in this study as rugosity - the development of superstructures and buttressing of cranial and facial bones. Cranial rugosity is often discussed purely as the expression of local genetic traits, rather than that rugosity features are muscle attachment sites for complex facial muscles. Where facial rugosity variation matches population boundaries, it may indeed simply be genetic, but it may also be population-specific cranio-facial activities, related to food processing, diet, or other use of the jaws. Typical locomotion or activity patterns producing indirect shock in the skull may also influence general cranial osteogenetic processes via a systemic effect on bone growth. So, as with postcranial rugosity, there may well be a genetic component to its variation, but this cannot theoretically be assumed to be the only influence on cranio-facial rugosity.

The twelve cranial scores (Table 6.1) are examined through the Kruskal-Wallis test, to establish how the categories age, sex, lifestyle, climate and continent influence cranial rugosity between sub-groups of the data set. The scores for craniofacial rugosity cannot be treated in the same statistical manner as the postcranial scores, since they do not all follow the same scale. For this reason, the components produced by Principal Components Analysis on these variables are used in multi-way ANOVA, rather than the traits themselves. Multi-way ANOVA is performed in

order to establish the extent to which the categories influence cranial rugosity, when variation in the other categories is controlled. These categories are the same as those described in Chapter 2.

Table 6.1 : Cranial scored variables

Code	Variable description
ST	Supraorbital torus
NS	Nasal saddle profile
IN	Infraglabellar notch profile
ZT	Zygomaxillary tubercule
TR	Zygomatic trigone
SK	Sagittal keeling
OA	Orbital superior margin angle
OB	Orbital superior lateral corner
OC	Orbital inferior margin angle
RO	Orbital rounding
OT	Occipital torus
OCR	Occipital crest

Kruskal-Wallis tests

By age, the only significant difference in cranial rugosity is between the under 30 and over 50 age categories for the occipital torus (Table 6.2). A higher proportion of the older age group have occipital torus scores of 5 or 6 than in the two younger categories, but the older age category is considerably smaller than the two younger categories (Figure 6.1).

By sex, males and females are significantly different for all cranial rugosity scores except nasal saddle, two of the orbit shape scores, and orbital floor rounding (Table

6.3). Most of the rest of the scores are for tuberosities, keeling and torus formation, and males generally score higher for these than females (Figure 6.2).

Table 6.2: Kruskal-Wallis test of age differences in cranial scores

	ST	NS	IN	ZT	TR	SK	OA	OB	OC	RO	OT	OCR
Under 30/30-50												
Chi-Square	3.518	1.637	.001	1.070	1.983	.530	3.165	.199	.174	3.489	1.967	.819
df	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.061	.201	.973	.301	.159	.467	.075	.655	.676	.062	.161	.366
30-50/Over 50												
Chi-Square	.130	.000	.318	.086	1.846	.155	.271	.102	1.812	.025	2.034	.173
df	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.718	.988	.573	.769	.174	.694	.603	.750	.178	.875	.154	.677
Under 30/Over 50												
Chi-Square	3.208	.809	.309	.165	.196	.010	.557	.361	2.516	1.093	5.141	1.311
df	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.073	.368	.578	.685	.658	.921	.456	.548	.113	.296	.023*	.252
All sample												
Chi-Square	4.940	1.882	.357	1.069	2.860	.549	3.215	.443	2.627	3.622	5.813	1.534
df	2	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.085	.390	.837	.586	.239	.760	.200	.801	.269	.164	.055	.464

* = p< .05

Figure 6.1 : Histogram of occipital torus score frequencies, by age category

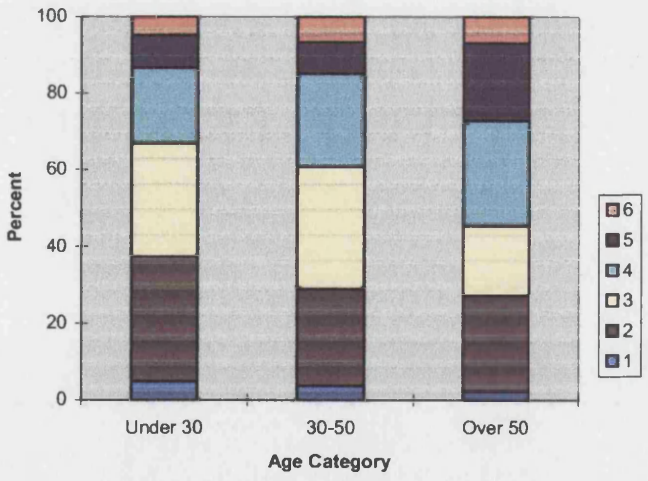


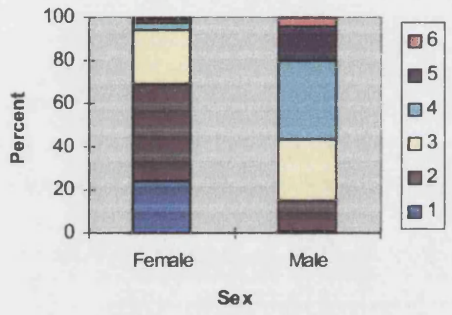
Table 6.3: Kruskal-Wallis test of sex differences in cranial scores

	ST	NS	IN	ZT	TR	SK	OA	OB	OC	RO	OT	OCR
Male/Female												
Chi-Square	117.443	.475	62.194	47.024	37.041	7.333	6.307	.066	.639	.804	25.178	6.080
df	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.000*	.491	.000*	.000*	.000*	.007*	.012*	.797	.424	.370	.000*	.014*

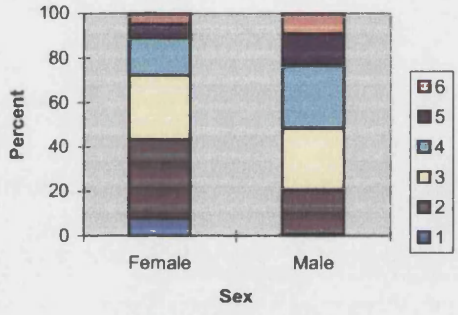
* = p< .05

Figure 6.2 : Histograms of a. supraorbital torus, b. occipital torus,

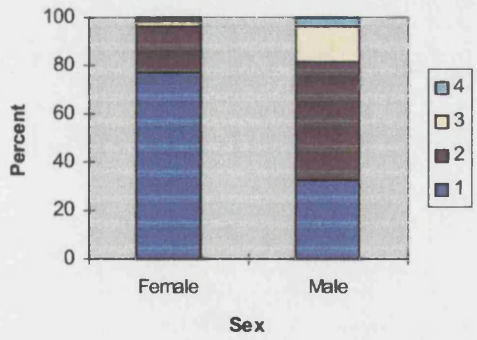
c. infraglabellar notch, and d. occipital crest counts by sex



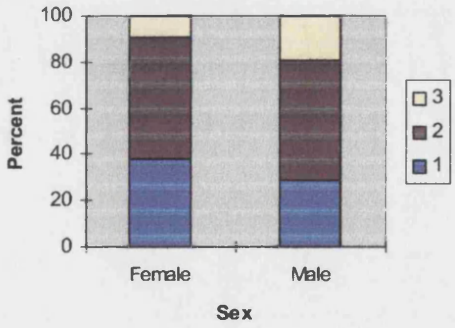
a. supraorbital torus score



b. occipital torus score



c. infraglabellar notch score



d. occipital crest score

By climate, no rugosity scores are significantly different between hot and temperate climates (Table 6.4), but between hot and cold, and temperate and cold climates there are several significant results. Nasal saddle, zygomaxillary tuberosity, sagittal

keeling, orbit inferior margin angle and occipital crest are significantly different between temperate and cold climates. The same five variables are significantly different within the whole population, and the same five variables plus zygomatic trigone are significantly different between hot and cold climates.

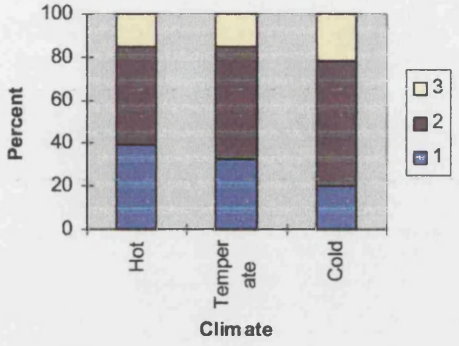
Table 6.4 : Kruskal-Wallis test of climate differences in postcranial scores

	ST	NS	IN	ZT	TR	SK	OA	OB	OC	RO	OT	OCR
Hot/Temp.												
Chi-Square	1.120	1.998	2.244	.066	2.103	1.726	.256	.677	1.358	.389	.324	.717
df	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.290	.157	.134	.797	.147	.189	.613	.410	.244	.533	.569	.397
Temp./Cold												
Chi-Square	.165	12.059	2.965	8.973	1.205	52.312	.004	.542	37.712	.426	.232	3.861
df	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.685	.001*	.085	.003*	.272	.000*	.949	.462	.000*	.514	.630	.049*
Hot/Cold												
Chi-Square	1.932	17.515	.295	7.520	4.925	37.210	.263	2.448	22.665	.015	.000	6.448
df	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. Sig.	.165	.000*	.587	.006*	.026*	.000*	.608	.118	.000*	.902	.987	.011*
All												
Chi-Square	2.089	19.671	3.860	10.017	5.264	56.753	.357	2.243	37.789	.588	.406	6.684
df	2	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.352	.000*	.145	.007*	.072	.000*	.837	.326	.000*	.745	.816	.035*

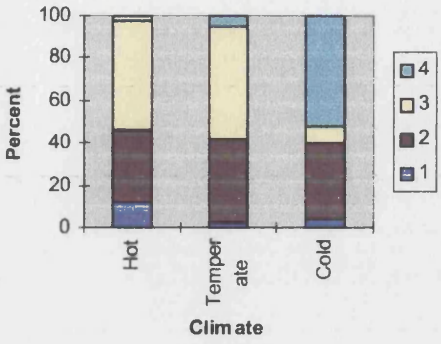
* = p< .05

The cold climate individuals tend to have a high proportion of the nasal saddle score 4 (Figure 6.3.b), which is the 'pinched' nasal bone trait recorded as being an Asian characteristic. This group contains a large number of Arctic Canadians, who may be considered to be closely related to the Northern Asian populations, hence the high proportion of this trait. The cold climate group also has a high proportion of moderate to strong sagittal keeling, and a high proportion with horizontal inferior orbit margins (Figure 6.2 c and d). The sagittal keeling may derive from masticatory stress exerted by the Arctic populations through processing animal skins. They also tend to have higher proportions of strong occipital crests and small zygomaxillary tuberosities (Figures 6.3. a and e.).

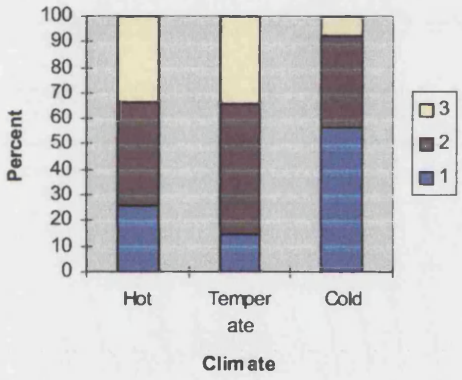
Figure 6.3 : Histograms of a. occipital crest, b. nasal saddle, c. orbit inferior margin angle, d. sagittal keeling and e. zygomaxillary tuberosity counts by climate



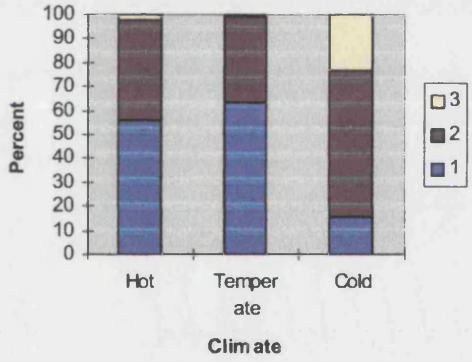
a. occipital crest score



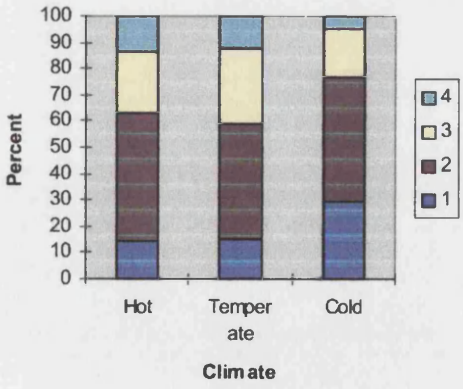
b. nasal saddle score



c. orbit inferior margin angle score



d. sagittal keeling score



e. zygomaxillary tuberosity score

Table 6.5: Kruskal-Wallis test of lifestyle differences in cranial scores

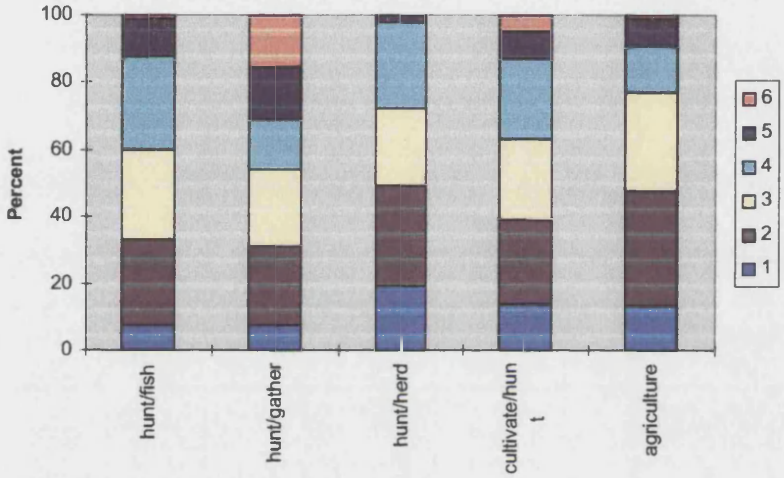
		ST	NS	IN	ZT	TR	SK	OA	OB	OC	RO	OT	OCR
HF/HG	Chi ^{2}	.676	2.601	3.914	7.726	.000	5.165	.509	1.109	.003	.860	3.650	17.573
1 df	Sig.	.411	.107	.048*	.005*	.985	.023*	.475	.292	.954	.354	.056	.000*
HF/HH	Chi ^{2}	5.358	.094	16.283	.955	.001	36.135	.017	1.519	15.365	20.183	3.699	1.138
1 df	Sig.	.021*	.759	.000*	.329	.977	.000*	.895	.218	.000*	.000*	.054	.286
HF/CH	Chi ^{2}	.576	2.102	.592	17.219	1.891	10.265	.699	.602	16.390	1.391	3.251	16.474
1 df	Sig.	.448	.147	.441	.000*	.169	.001*	.403	.438	.000*	.238	.071	.000*
HF/AG	Chi ^{2}	6.188	.058	8.487	.009	1.261	36.559	3.104	.633	52.894	14.458	.236	9.108
1 df	Sig.	.013*	.809	.004*	.924	.261	.000*	.078	.426	.000*	.000*	.627	.003*
HG/HH	Chi ^{2}	3.365	3.697	.183	4.668	.000	2.213	.533	.101	5.122	3.296	9.346	15.648
1 df	Sig.	.067	.055	.669	.031*	.984	.137	.466	.751	.024*	.069	.002*	.000*
HG/CH	Chi ^{2}	1.149	1.791	5.668	.594	.394	.618	.067	.949	4.246	1.935	1.706	4.042
1 df	Sig.	.284	.181	.017*	.441	.530	.432	.795	.330	.039*	.164	.191	.044*
HG/AG	Chi ^{2}	3.175	4.435	.446	8.098	.261	.354	2.341	.227	14.877	1.185	4.638	6.942
1 df	Sig.	.075	.035*	.504	.004*	.609	.552	.126	.634	.000*	.276	.031*	.008*
HH/CH	Chi ^{2}	2.128	2.148	20.412	6.244	1.144	13.441	.606	1.757	.590	22.613	13.714	14.539
1 df	Sig.	.145	.143	.000*	.012*	.285	.000*	.436	.185	.442	.000*	.000*	.000*
HH/AG	Chi ^{2}	.081	.004	4.198	1.045	.837	2.455	1.525	.113	4.666	1.387	2.417	9.542
1 df	Sig.	.776	.949	.040*	.307	.360	.117	.217	.736	.031*	.239	.120	.002*
CH/AG	Chi ^{2}	2.031	3.375	12.556	16.518	5.360	8.015	5.550	1.319	12.758	18.108	5.146	1.349
1 df	Sig.	.154	.066	.000*	.000*	.021*	.005*	.018*	.251	.000*	.000*	.023*	.245
All	Chi ^{2}	10.356	6.764	31.294	27.658	5.403	56.364	7.039	3.446	60.711	38.495	17.134	36.979
4 df	Sig.	.035*	.149	.000*	.000*	.248	.000*	.134	.486	.000*	.000*	.002*	.000*

* = p <.05 HF: Hunt/fish, HG: Hunt/gather, HH: Hunt/herd, CH: Cultivate/hunt, AG: Agriculture, All: Whole sample

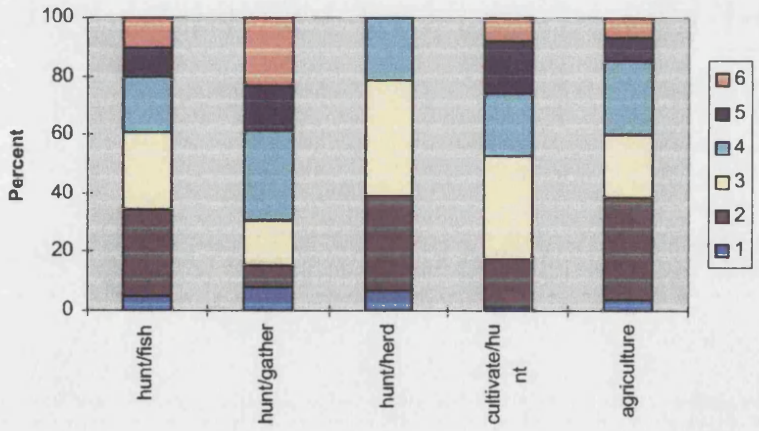
The pattern of significant differences between categories by lifestyle is very complex (Table 6.5). Zygomatic trigone, orbit superior margin and superior lateral corner are not significantly different between any categories, but all the rest of the scores show some variation with lifestyle. Supraorbital torus score shows significant difference between hunt/fish hunt/herd groups, and hunt/fish and agricultural groups, with the hunt/fish people having a higher proportion of high ST scores (Figure 6.6a). Nasal saddle only differs significantly between hunt/gather and agricultural groups, but the

hunt/gather group is particularly small. The occipital torus shows significant differences in variance between several groups, and is notable in that the hunt/herd category have none of the highest two scores, while the other lifestyle categories show varied proportions of all score grades (Figure 6.4b).

Figure 6.4 : Histograms of a. supraorbital torus and b. occipital torus counts by lifestyle



a.



b.

The continent-based analysis shows similar complexity. The European continent shows most significant differences with other continents, having 5 differences compared to Africa, 8 compared to the Americas or Asia, and 7 compared with Australasia. Africa shows the least significant differences with other continents, having a minimum of 3 and a maximum of 5 significant differences (Table 4.10). Like the lifestyle categorisation, the continent categories are unbalanced in size, so strong conclusions are difficult.

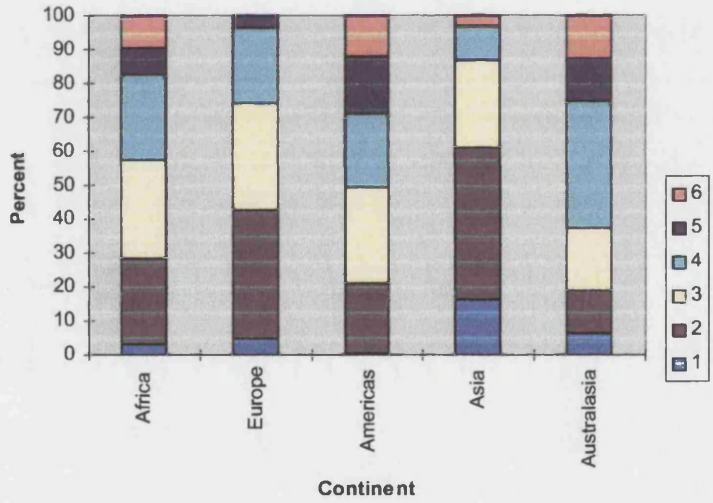
Table 6.6 : Kruskal-Wallis test of continent differences in cranial scores

		ST	NS	IN	ZT	TR	SK	OA	OB	OC	RO	OT	OCR
AF/EU	Chi^2	.002	.623	10.148	.906	6.078	2.085	.745	4.451	.983	5.672	6.433	.659
1 d.f.	Sig.	.966	.430	.001*	.341	.014*	.149	.388	.035*	.322	.017*	.011*	.417
AF/AM	Chi^2	5.376	.485	4.701	.358	.016	26.124	1.648	.208	21.517	7.220	2.447	.917
1 d.f.	Sig.	.020*	.486	.030*	.549	.900	.000*	.199	.649	.000*	.007*	.118	.338
AF/AS	Chi^2	.090	5.737	2.565	.956	.025	.163	1.725	.082	11.185	2.924	12.377	2.197
1 d.f.	Sig.	.764	.017*	.109	.328	.875	.686	.189	.774	.001*	.087	.000*	.138
AF/AU	Chi^2	4.514	4.196	4.152	4.349	.898	.962	.894	3.409	6.408	.388	1.389	3.737
1 d.f.	Sig.	.034*	.041*	.042*	.037*	.343	.327	.344	.065	.011*	.533	.239	.053
EU/AM	Chi^2	6.320	1.985	34.370	3.170	9.718	47.082	.035	8.362	15.240	32.691	22.612	.001
1 d.f.	Sig.	.012*	.159	.000*	.075	.002*	.000*	.852	.004*	.000*	.000*	.000*	.978
EU/AS	Chi^2	.042	5.019	15.549	.045	5.633	.537	4.157	3.487	7.580	14.996	4.465	.911
1 d.f.	Sig.	.838	.025*	.000*	.832	.018*	.464	.041*	.062	.006*	.000*	.035*	.340
EU/AU	Chi^2	4.980	2.757	.064	7.011	.454	3.834	.111	.386	3.854	5.083	7.531	6.810
1 d.f.	Sig.	.026*	.097	.800	.008*	.500	.050*	.739	.535	.050*	.024*	.006*	.009*
AM/AS	Chi^2	2.757	9.016	.024	2.363	.001	18.262	7.418	.003	.000	.073	23.339	1.081
1 d.f.	Sig.	.097	.003*	.878	.124	.976	.000*	.006*	.953	.990	.787	.000*	.298
AM/AU	Chi^2	1.520	4.391	10.943	3.520	1.216	4.458	.083	5.086	.209	.877	.113	8.053
1 d.f.	Sig.	.218	.036*	.001*	.061	.270	.035*	.774	.024*	.648	.349	.737	.005*
AS/AU	Chi^2	3.580	.362	7.783	6.441	1.369	1.376	4.335	2.595	.159	.436	10.522	8.718
1 d.f.	Sig.	.058	.547	.005*	.011*	.242	.241	.037*	.107	.691	.509	.001*	.003*
ALL	Chi^2	12.757	13.828	43.275	10.043	12.058	62.392	7.826	12.777	32.486	35.789	40.475	10.281
4 d.f.	Sig.	.013*	.008*	.000*	.040*	.017*	.000*	.098	.012*	.000*	.000*	.000*	.036*

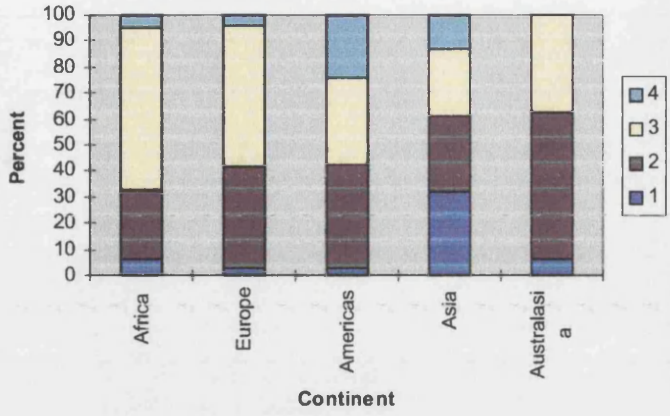
* = $p < .05$ AF: Africa, EU: Europe, AM: Americas, AS: Asia, AU: Australasia, ALL: Whole sample

The most interesting patterns are graphed below (Figure 6.5), and demonstrate the size unbalance in the continent categories, as well as how the continents differ in the proportions of each score grade. Europe has no individuals with the highest occipital torus score, but Europe and America are the only continents where strong sagittal keeling is present. All continents except Australasia show nasal saddle score 4, the pinched profile supposed to be typical of Asians. The Asian continent is distinct in having no representatives with the lowest zygomatic trigone score.

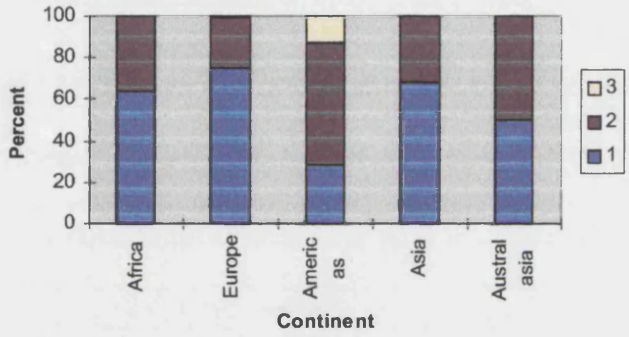
Figure 6.5 : Histograms of a. occipital torus, b. nasal saddle, c. sagittal keeling and d. zygomatic trigone counts by continent



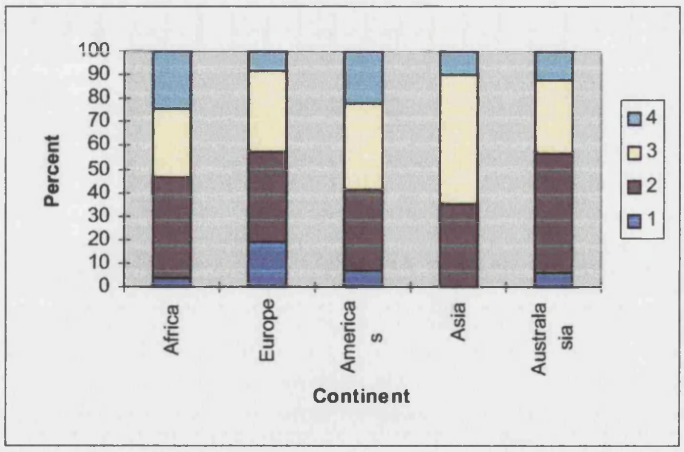
a.occipital torus



b. nasal saddle



c.sagittal keeling



d. zygomatic trigone

Principal Components Analysis

The twelve cranial variables were entered into a Principal Components Analysis, utilising Varimax rotation. The rotation converged in 6 iterations, and the analysis detected 5 components from 291 individual cases (Table 6.7). All components were plotted on bi-variate scatters by age, sex, climate, lifestyle, continent, region and population. Only component 1 showed any separation of categories, when plotted by sex (Figure 6.6). Component 1 includes the scores for supraorbital torus (ST), zygomaxillary tuberosity (ZT), occipital torus (OT) and zygomatic trigone (TR), which are the major craniofacial superstructures scored. The score for infraglabella notch (IN) loads across several components, particularly 1 and 3 (Table 6.8). Males score high on component 1, while females score low, supporting the notion that male craniofacial superstructures are more developed than those of females.

However, this finding also supports the assertion that these scores are not independent of size, and that it is simply the larger crania of males that results in them being given higher scores for these superstructures. To test the size-independence of the cranial scores, component 1 was scaled by cranial module (see below). The resulting variable is normally distributed, and the difference between males and females was tested using ANOVA with the Tamhane post-hoc test.

Size-corrected Component 1 = Component 1 / Cranial module

Males remain significantly higher than females on the size-corrected component 1 (ANOVA p = .000, Tamhane p = .000). This indicates that the difference between males and females is a rugosity difference rather than a size difference.

Table 6.7: Component loading for principal components analysis, cranial scores

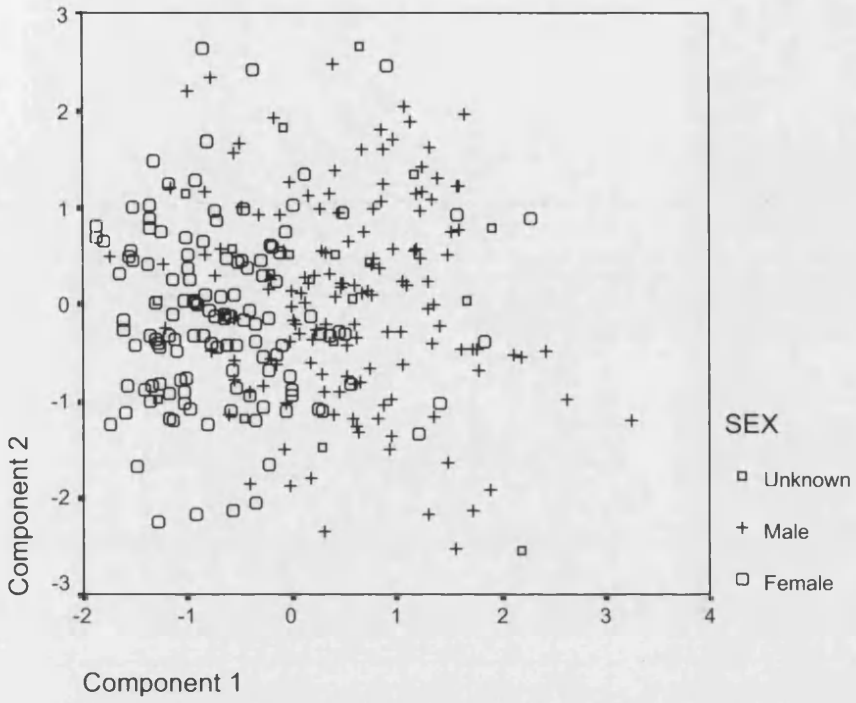
Component	Variables loaded	Rotation Sums of Squared Loadings		
		Total	% of Variance	Cumulative %
1	ST, ZT, OT, TR, IN	2.379	19.822	19.822
2	OCR, RO (-ve)	1.250	10.418	30.240
3	OC, OA	1.207	10.062	40.301
4		1.207	10.061	50.362
5	OB	1.188	9.902	60.264

Table 6.8: Rotated Component Matrix: Cranial Scores

Component	1	2	3	4	5
ST	.787			.153	
ZT	.694			-.114	-.127
OT	.622			.195	.301
TR	.595		-.119		.275
IN	.581	.164	.430		-.304
OC		.845			
OA	.212	.594			.348
RO	.176		-.734		.101
OCR	.139		.674	.147	.198
NS	-.180	.250		.761	
SK	.256	-.281		.716	
OB					.852

(Sorted by size, values less than 0.1 not shown)

Figure 6.6 : Principal Components 1 and 2 for cranial scores analysis, by sex



Five-way ANOVA

The five-way ANOVA is performed on the raw components from the principal components analysis, rather than on the variables themselves, since the components are scale data rather than scores, and are normally distributed. Component 1 shows the above-mentioned significant influence of sex on craniofacial rugosity, even when other categories are held stable (Table 6.9). Components 2, 3 and 4 show no significant influences from any category.

There are no significant interactions between the categories in their influence on the first principal component, representing general cranio-facial superstructures. However, component 2, on which occipital crest and orbit rounding load strongly, shows significant interactions between climate and continent, and climate and sex. Any climatic influence on these rugosity features is therefore mediated both by sex and the continent in which the individual is found. Alternatively, sexual and genetic (continental) differences in rugosity are affected by climate. Neither the third nor fourth principal components show any significant interactions.

Eight cranial scores will be carried into the Discriminant Function Analysis in Chapter 7. These are supraorbital torus, zygomatic trigone, occipital torus, zygomaxillary tuberosity, occipital crest, orbit rounding, lateral superior orbit corner and orbit inferior margin. These variables load strongly on the principal components analysis, and show the best discrimination between categories in the initial analyses.

Table 6.9: Results of five-way ANOVA on components of craniofacial rugosity

Component 1					**Component 2**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	109.645	205			none	158.868	205		
age	140.687	251	1.048	**ns**	age	194.774	251	1.001	**ns**
sex	222.93	246	1.694	**0.01**	sex	206.863	246	1.085	**ns**
lifestyle	123.04	230	1.000	**ns**	lifestyle	180.743	230	1.014	**ns**
climate	133.514	221	1.130	**ns**	climate	176.205	221	1.029	**ns**
continent	117.75	222	0.992	**ns**	continent	170.048	222	0.988	**ns**

Component 3					**Component 4**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	170.185	205			none	157.657	205		
age	199.684	251	0.958	**ns**	age	194.099	251	1.006	**ns**
sex	201.834	246	0.988	**ns**	sex	189.194	246	1.000	**ns**
lifestyle	205.993	230	1.079	**ns**	lifestyle	187.091	230	1.058	**ns**
climate	182.304	221	0.994	**ns**	climate	167.265	221	0.984	**ns**
continent	186.817	222	1.014	**ns**	continent	201.573	222	1.181	**ns**

Population profiles

The populations show very different profiles for each of the major components produced in the PCA. Those that have high positions on principal component 1 include the Australian, Illinois, Slavic, Sadlermiut and South American groups (Figure 6.7). These populations therefore have strong development of the tori, tuberosities and trigones of the craniofacial region. The second principal component represents occipital crest and orbit floor rounding, and the populations that have high mean scores include the Avar and Slavic groups (Figure 6.8). These are two populations from Central Europe, and this common high position may reflect relatedness in terms of shared facial and nuchal features. However, the Inuit and Sadlermiut do not score similarly on this component, despite their close relationship.

Figure 6.7 : Histogram of Principal Component 1 for Cranial Scores, by population

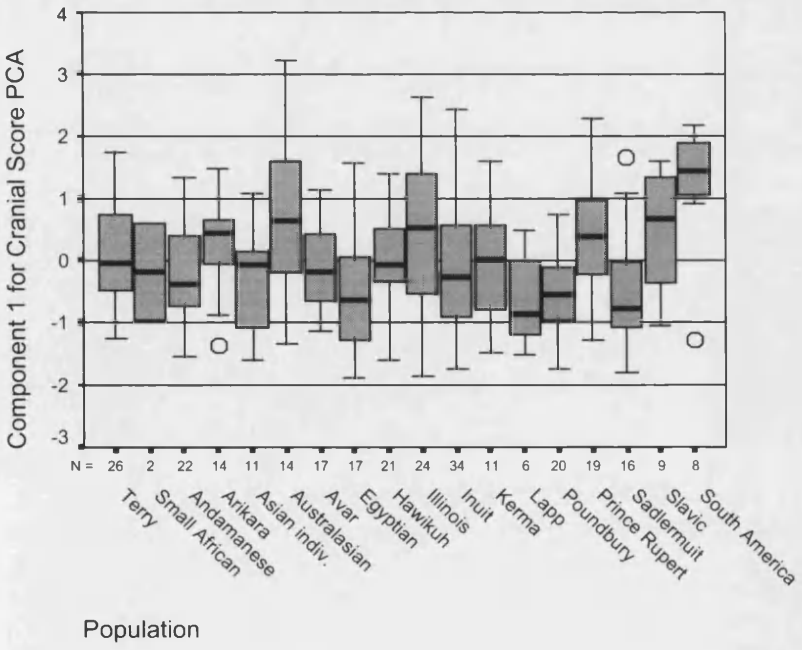
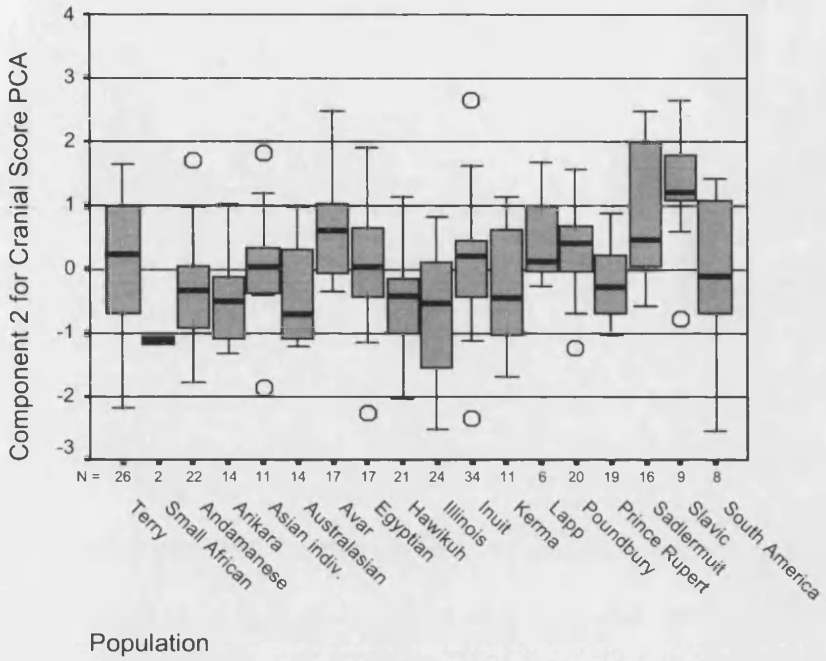


Figure 6.8 : Histogram of Principal Component 2 for Cranial Scores, by population



The third and fourth principal components refer mainly to orbit shape, and as such show strong diversity between populations with little apparent reflection from robusticity (Figures 6.9 and 6.10). On the third component, the larger the score, the more diverged horizontal are the inferior and superior orbit margins. High scores on the fourth principal component reflects divergence from a right-angle at the superior lateral orbit corner. Only the Poundbury population have a high proportion of right-angled orbits. The population profiles for orbit shape do not follow the same patterns as those for the first two components which might more reasonably be understood to be representing cranio-facial superstructures.

Figure 6.9 : Histogram of Principal Component 3 for Cranial Scores, by population

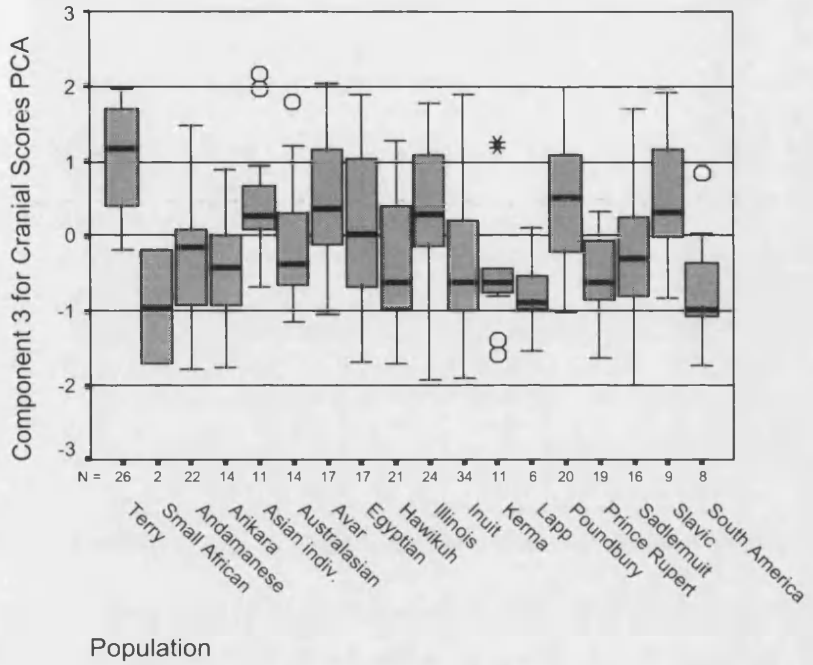
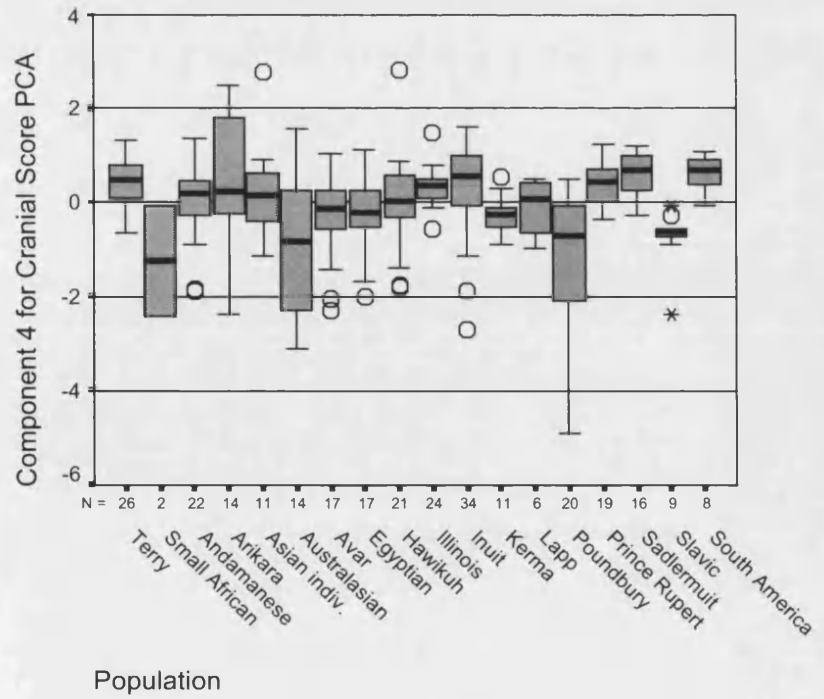


Figure 6.10 : Histogram of Principal Component 4 for Cranial Scores, by population



Summary

The scores for the zygomatic trigone, the supraorbital and occipital tori and the zygomaxillary tuberosity load together in principal components analysis. They form the only aggregated rugosity score that shows any significant influence in the five-way ANOVA analysis. Males are significantly more rugged in the cranium than females, once other influences are held constant. These scores are most obviously related to hypertrophy, since higher scores reflect larger superstructures in these regions.

However, the scores that load on the first principal component are not directly associated with muscle attachment sites, and so do not match the postcranial rugosity scores directly. High scoring individuals on the second principal component have large occipital crests and angular inferior orbit margins. The occipital crest score is also related to hypertrophy, but is directly related to the attachment site for the nuchal muscles. However, OCR does not load with the other hypertrophy scores, so cannot be considered to be part of the same complex.

The first principal component may therefore be reflecting cranial sexual dimorphism rather than rugosity in the sense assessed in the postcrania. The occipital crest score is the only one that can be easily associated with a muscle attachment site, and so match the postcranial scores directly.

The scores loading on principal components 3 and 4 represent subtleties of orbit shape, which could be subject to indirect influence from hypertrophic build-up of the supraorbital torus, and zygomatic structures. Since these scores do not load with the tori and zygomatic structures, this is unlikely. Nonetheless, the diversity displayed in population profiles for these and the second component suggests that they are all distinctive features of cranio-facial morphology, with potential utility for population identification. The scores loading on the first principal component may be biased by the sex ratio within the population of interest, or be involved in sex determination, and so less useful for identification purposes.

Principal Components Analysis

The twelve cranial variables were entered into a Principal Components Analysis, utilising Varimax rotation. The rotation converged in 6 iterations, and the analysis detected 5 components from 291 individual cases (Table 6.7). All components were plotted on bi-variate scatters by age, sex, climate, lifestyle, continent, region and population. Only component 1 showed any separation of categories, when plotted by sex (Figure 6.6). Component 1 includes the scores for supraorbital torus (ST), zygomaxillary tuberosity (ZT), occipital torus (OT) and zygomatic trigone (TR), which are the major craniofacial superstructures scored. The score for infraglabella notch (IN) loads across several components, particularly 1 and 3 (Table 6.8). Males score high on component 1, while females score low, supporting the notion that male craniofacial superstructures are more developed than those of females.

However, this finding also supports the assertion that these scores are not independent of size, and that it is simply the larger crania of males that results in them being given higher scores for these superstructures. To test the size-independence of the cranial scores, component 1 was scaled by cranial module (see below). The resulting variable is normally distributed, and the difference between males and females was tested using ANOVA with the Tamhane post-hoc test.

Size-corrected Component 1 = Component 1 / Cranial module

Males remain significantly higher than females on the size-corrected component 1 (ANOVA p = .000, Tamhane p = .000). This indicates that the difference between males and females is a rugosity difference rather than a size difference.

Table 6.7: Component loading for principal components analysis, cranial scores

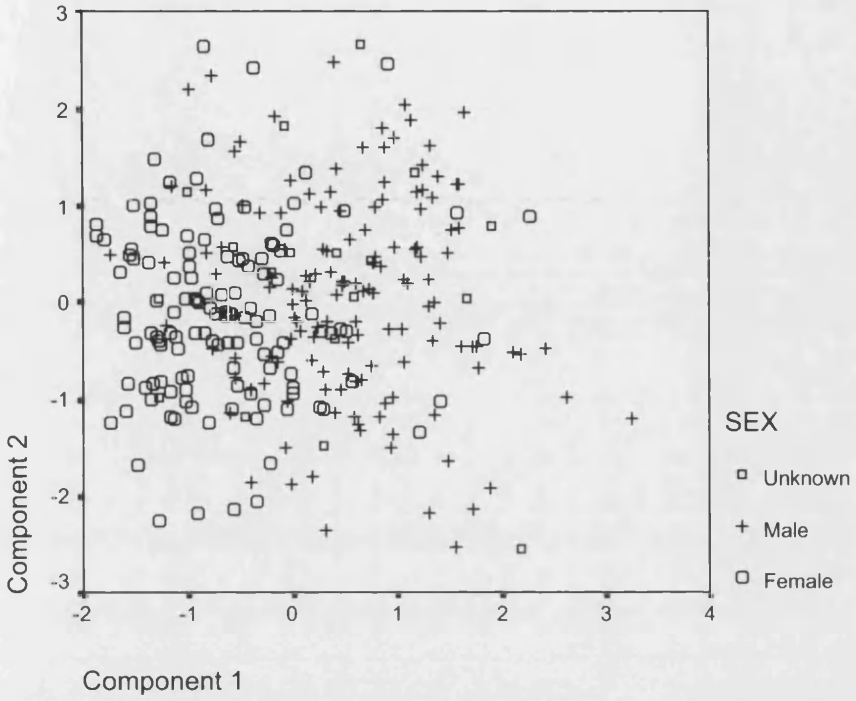
Component	Variables loaded	Rotation Sums of Squared Loadings		
		Total	% of Variance	Cumulative %
1	ST, ZT, OT, TR, IN	2.379	19.822	19.822
2	OCR, RO (-ve)	1.250	10.418	30.240
3	OC, OA	1.207	10.062	40.301
4		1.207	10.061	50.362
5	OB	1.188	9.902	60.264

Table 6.8: Rotated Component Matrix: Cranial Scores

Component	1	2	3	4	5
ST	.787			.153	
ZT	.694			-.114	-.127
OT	.622			.195	.301
TR	.595		-.119		.275
IN	.581	.164	.430		-.304
OC		.845			
OA	.212	.594			.348
RO	.176		-.734		.101
OCR	.139		.674	.147	.198
NS	-.180	.250		.761	
SK	.256	-.281		.716	
OB					.852

(Sorted by size, values less than 0.1 not shown)

Figure 6.6 : Principal Components 1 and 2 for cranial scores analysis, by sex



Five-way ANOVA

The five-way ANOVA is performed on the raw components from the principal components analysis, rather than on the variables themselves, since the components are scale data rather than scores, and are normally distributed. Component 1 shows the above-mentioned significant influence of sex on craniofacial rugosity, even when other categories are held stable (Table 6.9). Components 2, 3 and 4 show no significant influences from any category.

There are no significant interactions between the categories in their influence on the first principal component, representing general cranio-facial superstructures. However, component 2, on which occipital crest and orbit rounding load strongly, shows significant interactions between climate and continent, and climate and sex. Any climatic influence on these rugosity features is therefore mediated both by sex and the continent in which the individual is found. Alternatively, sexual and genetic (continental) differences in rugosity are affected by climate. Neither the third nor fourth principal components show any significant interactions.

Eight cranial scores will be carried into the Discriminant Function Analysis in Chapter 7. These are supraorbital torus, zygomatic trigone, occipital torus, zygomaxillary tuberosity, occipital crest, orbit rounding, lateral superior orbit corner and orbit inferior margin. These variables load strongly on the principal components analysis, and show the best discrimination between categories in the initial analyses.

Table 6.9: Results of five-way ANOVA on components of craniofacial rugosity

Component 1					**Component 2**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	109.645	205			none	158.868	205		
age	140.687	251	1.048	**ns**	age	194.774	251	1.001	**ns**
sex	222.93	246	1.694	**0.01**	sex	206.863	246	1.085	**ns**
lifestyle	123.04	230	1.000	**ns**	lifestyle	180.743	230	1.014	**ns**
climate	133.514	221	1.130	**ns**	climate	176.205	221	1.029	**ns**
continent	117.75	222	0.992	**ns**	continent	170.048	222	0.988	**ns**

Component 3					**Component 4**				
category excluded	SS	df	F	sig.	category excluded	SS	df	F	sig.
none	170.185	205			none	157.657	205		
age	199.684	251	0.958	**ns**	age	194.099	251	1.006	**ns**
sex	201.834	246	0.988	**ns**	sex	189.194	246	1.000	**ns**
lifestyle	205.993	230	1.079	**ns**	lifestyle	187.091	230	1.058	**ns**
climate	182.304	221	0.994	**ns**	climate	167.265	221	0.984	**ns**
continent	186.817	222	1.014	**ns**	continent	201.573	222	1.181	**ns**

Population profiles

The populations show very different profiles for each of the major components produced in the PCA. Those that have high positions on principal component 1 include the Australian, Illinois, Slavic, Sadlermiut and South American groups (Figure 6.7). These populations therefore have strong development of the tori, tuberosities and trigones of the craniofacial region. The second principal component represents occipital crest and orbit floor rounding, and the populations that have high mean scores include the Avar and Slavic groups (Figure 6.8). These are two populations from Central Europe, and this common high position may reflect relatedness in terms of shared facial and nuchal features. However, the Inuit and Sadlermiut do not score similarly on this component, despite their close relationship.

Figure 6.7 : Histogram of Principal Component 1 for Cranial Scores, by population

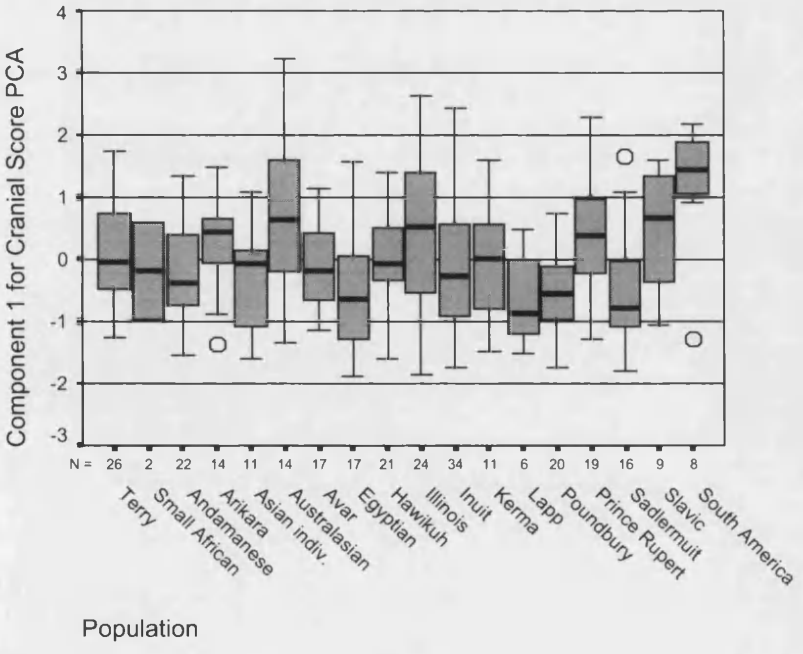
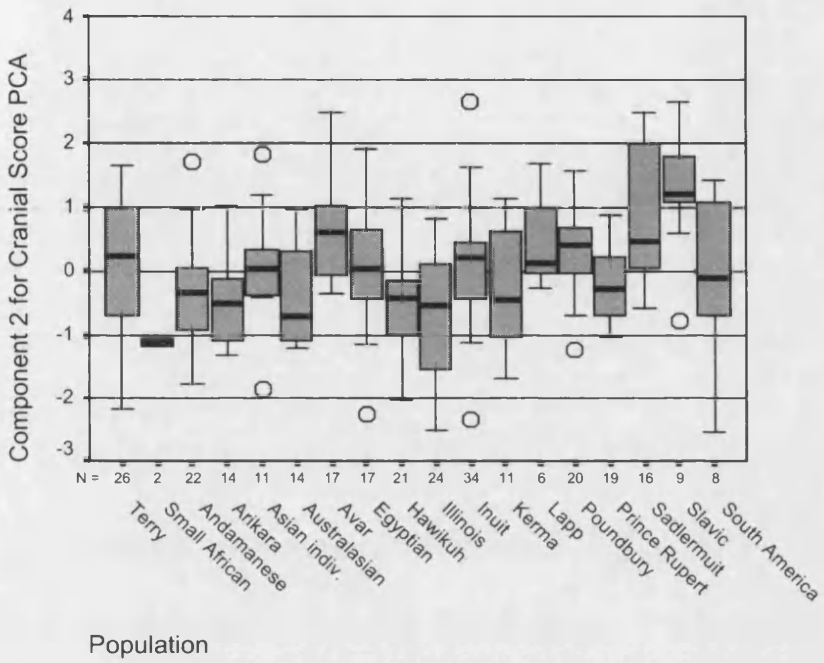


Figure 6.8 : Histogram of Principal Component 2 for Cranial Scores, by population



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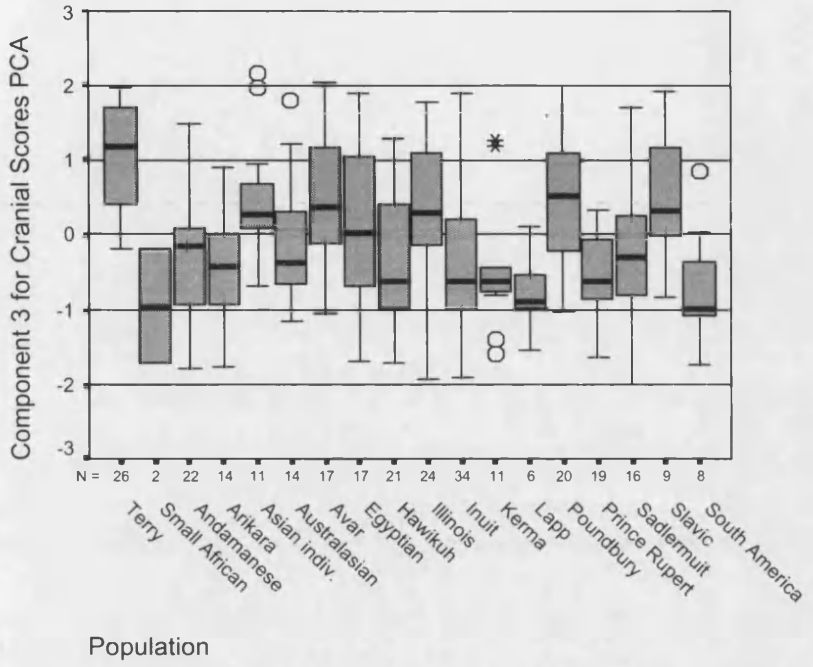
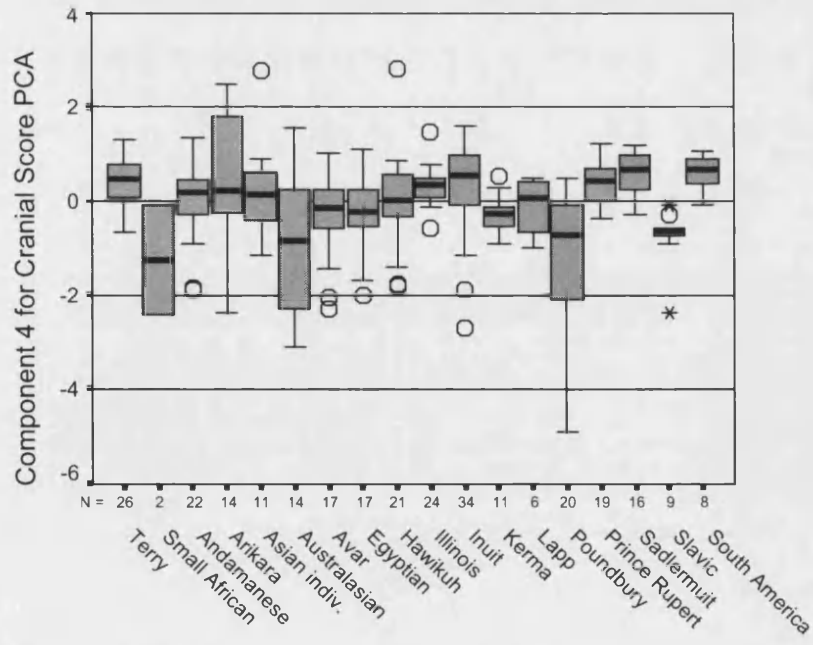


Figure 6.10 : Histogram of Principal Component 4 for Cranial Scores, by population



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Chapter 7 : Results Synthesis

In this chapter, the results from the previous four chapters on each of the data types are integrated, and the four different kinds of data are compared. Cranial and postcranial variables including size, shape, robusticity and rugosity are explored independently, and then cranial and postcranial variables are regressed against one another. In all cases, least-squares linear regression analysis provides a good assessment of the strength of any relationship between variables.

Comparing rugosity and robusticity directly is difficult, given the differences in data type. The aggregated z-scores produced for cranial and postcranial rugosity are used here, since they are normally distributed and scalar in nature. Finally, a discriminant function analysis is performed for each kind of data, and by cranial and postcranial regions of the body. This allows differences in the pattern and success of classification to be examined in a comparable fashion.

Comparisons between cranial variables

For the cranial analyses, there are just eight relevant variables to explore. Cranial module reflects size, cranial index reflects shape, the aggregated z-score for cranial scores reflects rugosity, and the five cranio-facial robusticity indices represent size-corrected robusticity.

Linear regressions against cranial size and shape

Cranial shape and size (cranial index and module) show a significant relationship, with strong explanatory power (Table 7.1). When plotted by continent, a clear pattern emerges (Figure 7.1). The European crania have consistently higher cranial indices for their size, and are broad for their size, while the American crania are consistently long for their size. Both cranial module and index have significant relationships with the aggregated cranial rugosity score, but these relationships have low explanatory power.

Table 7.1 : Least-squares linear regression statistics for cranial robusticity and rugosity against cranial shape and cranial size

Dependent variable	Independent variable	Intercept	Slope	Sig.	R squared
Cranial index	Cranial module	-245.995	3.289	.000 **	.871
Cranial rugosity	Cranial module	-4.302	.029	.000 **	.168
Gnathic index	Cranial module	116.279	-.127	.009 **	.023
Zygomatic breadth index	Cranial module	.8876	.0005	.913	-.004
Nasal height index	Cranial module	.346	.0007	.042*	.012
Malar height index	Cranial module	.274	-.0000	.444	-.002
Forehead breadth index	Cranial module	.746	.0000	.668	-.003
Cranial rugosity	Cranial index	102.812	-.022	.000 **	.006
Gnathic index	Cranial index	.891	-.0000	.121	-.004
Zygomatic breadth index	Cranial index	.429	.0001	.821	.000
Nasal height index	Cranial index	.265	.0001	.349	.002
Malar height index	Cranial index	.705	.0003	.235	.025
Forehead breadth index	Cranial index	-1.481	.0061	.005 **	.090

* = p < .05, ** = p < .01

The cranial robusticity indices generally show no significant relationships with cranial size (module) or shape (index) (Table 7.1). The exceptions are gnathic index and

nasal height index, which show significant relationships with cranial size, and forehead breadth index, which shows a significant relationship with cranial shape. However, these also have a low explanatory power.

Males have a tendency to have both higher aggregated cranial rugosity and larger crania than females (Figure 7.2), but there is considerable overlap between the sexes. The general positive trend between cranial size and rugosity is observable when plotted with just the population means (Figure 7.3). Populations with larger mean cranial module tend to have higher mean rugosity, although there is considerable scatter, and no obvious pattern by continent, climate or lifestyle.

Figure 7.1 : Cranial index against cranial module, by continent.

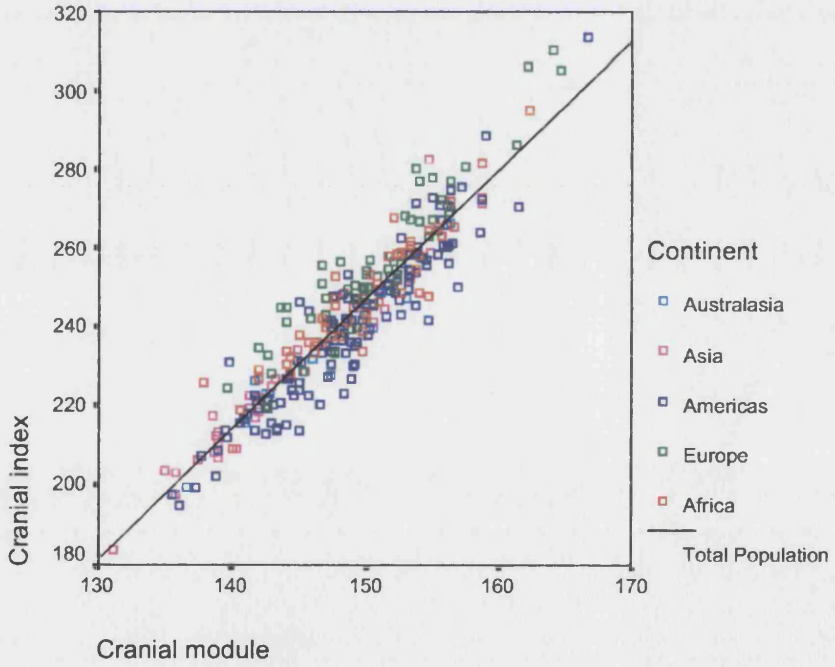


Figure 7.2 : Cranial rugosity against cranial module, by sex

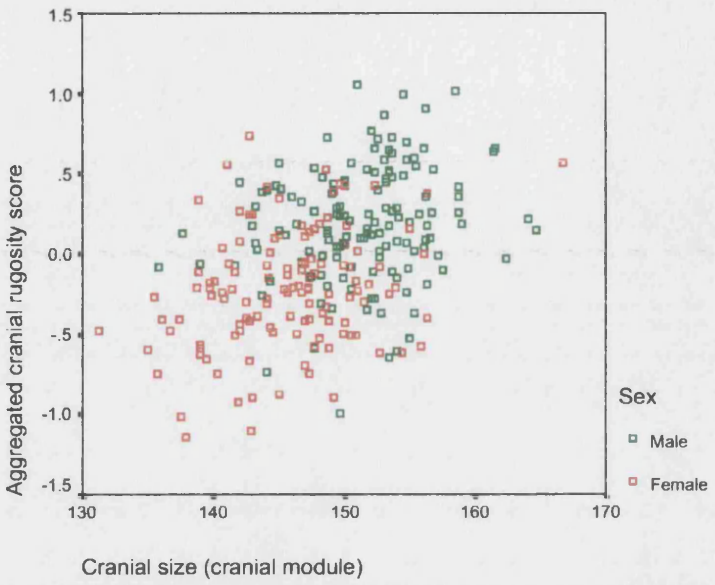
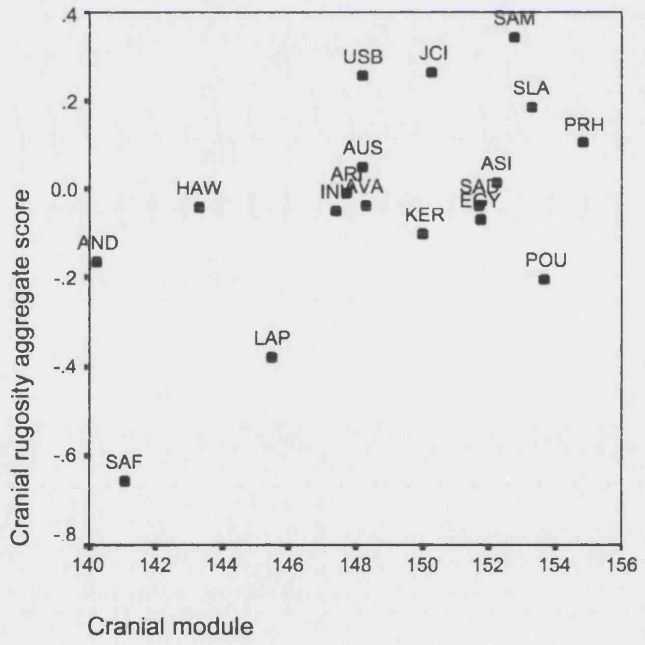


Figure 7.3 : Cranial rugosity against cranial module, population means



Linear regressions against cranial rugosity

Cranial rugosity shows significant relationships with only two cranial robusticity indices (Table 7.2). These are zygomatic breadth index and nasal height index, but the explanatory power of these relationships is very low. This holds true even if the aggregated cranio-facial rugosity score is replaced in the analyses with the independent z-scores for each of the cranial rugosity scores, or if the full data set is reduced to population means (not shown here). When plotted as bivariate scatters, none of these pairs of variables show any patterns by age, sex, climate, lifestyle, continent or population.

Table 7.2 : Linear regression statistics for cranial robusticity against cranial rugosity

Dependent variable	Independent variable	Intercept	Slope	Sig.	R squared
Gnathic index	Cranial rugosity aggregate	97.495	-.296	.670	-.003
Zygomatic breadth index		.883	.027	.000 **	.063
Nasal height index		.452	.018	.000 **	.047
Malar height index		.242	.006	.161	.004
Forehead breadth index		.767	.000	.904	-.004

* = p < .05, ** = p < .01

Comparisons between postcranial variables

For the postcranial analyses, the three body shape indices, crural, brachial and claviculo-radial, represent body proportions, and postcranial robusticity is represented by the full set of diaphyseal and epiphyseal robusticity indices. Postcranial rugosity is represented by the four aggregate rugosity scores prepared

above, which summarise rugosity of the forearm, leg, upper arm and shoulder, and wear rugosity. Issues of body size are discussed in Chapter 3, and are not included here.

Linear regressions against body shape indices

There are significant relationships between each of the body shape indices and almost all of the diaphyseal robusticity indices (Table 7.3). The exception is the non-significant relationship between clavicle robusticity and crural index. Although they are otherwise significant, none of the relationships have an r-squared value over .3, which indicates that these trends have low explanatory power. The same is true for the relationships between body shape and epiphyseal robusticity. All are significant, except for those between humerus distal joint index and claviculo-radial index, femur distal joint index and brachial index, and humerus proximal joint index and brachial index. However, none has strong explanatory power.

There are also some significant relationships between the aggregated postcranial rugosity scores and the body shape indices. Brachial index is significantly related to the second aggregated score, representing leg rugosity. Crural index is significantly related to the third aggregated score, representing upper arm and shoulder rugosity. Claviculo-radial index shows significant relationships with the first aggregated score, representing forearm rugosity, as well as the second and third aggregated scores.

Table 7.3 : Linear regression statistics for postcranial rugosity and robusticity against body shape indices

Dependent variable	Independent variable Brachial Index				Independent variable Crural Index				Independent variable Clavicular-radial Index			
	Intercept	Slope	Sig.	R^2	Intercept	Slope	Sig.	R^2	Intercept	Slope	Sig.	R^2
TMSRI	18.609	-5.830	.000 **	.045	20.248	-7.426	.000 **	.052	8.703	8.933	.000 **	.174
UMSRI	17.498	-7.359	.000 **	.056	19.261	-8.985	.000 **	.060	4.963	11.320	.000 **	.216
USBRI	24.388	-12.79	.000 **	.091	27.003	-15.068	.000 **	.091	4.609	16.488	.000 **	.242
RMSRI	20.453	-11.79	.000 **	.159	20.024	-10.311	.000 **	.089	4.167	12.087	.000 **	.264
CMSRI	10.190	6.694	.002 **	.024	16.506	-1.560	.544	-.002	21.792	-10.622	.000 **	.101
HMSRI	18.173	-6.622	.000 **	.045	21.087	-9.731	.000 **	.072	6.940	10.113	.000 **	.172
FMSRI	15.743	-4.481	.000 **	.045	14.686	-2.810	.029 *	.011	8.477	6.308	.000 **	.146
FSTRI	17.315	-5.898	.000 **	.049	15.583	-3.285	.040 *	.009	6.993	9.511	.000 **	.211
TPJI	17.342	-.861	.000 **	-.002	33.448	-15.498	.000 **	.162	14.796	9.992	.000 **	.139
FPJI	26.971	-8.020	.000 **	.053	13.570	-4.070	.000 **	.040	7.333	4.753	.000 **	.125
FDJI	12.834	-3.409	.521	.039	19.618	-3.632	.027 *	.012	14.658	3.268	.003 **	.025
HPJI	15.789	-2.179	.059	.007	19.668	-6.835	.000 **	.070	10.689	5.560	.000 **	.102
HDJI	11.674	10.255	.000 **	.089	23.791	-5.676	.009 **	.017	18.112	1.779	.255	.001
RPJI	16.053	-8.593	.000 **	.201	15.628	-7.367	.000 **	.108	4.571	8.197	.000 **	.290
UDJI	17.461	-11.80	.000 **	.288	14.970	-7.766	.000 **	.113	2.357	10.200	.000 **	.412
Crural	.615	.250	.000 **	.084								
Clav-rad	1.145	-.702	.000 **	.312	.938	-.387	.000 **	.066				
Agg. 1	-2.157	2.989	.291	.000	-7.56	.979	.768	-.003	-2.850	4.602	.041 *	.010
Agg. 2	-6.292	8.541	.015 *	.015	-4.224	5.284	.197	.002	-5.231	8.300	.002 **	.025
Agg. 3	3.308	-4.544	.116	.005	8.956	-11.254	.001 **	.031	-7.598	12.039	.000 **	.085
Agg. 4	1.332	-1.802	.377	-.011	1.145	-1.430	.543	-.002	-1.864	2.969	.058	.009

* = $p < .05$, ** = $p < .01$

The fourth aggregated score, which represents upper body wear, shows no significant relationships with body shape. The statistically significant relationships here are very weak, with none showing r-squared values above .08.

Plotted by climate, it is clear that both high epiphyseal robusticity at the distal ulna and a high claviculo-radial index (i.e. a broad torso), are associated with cooler climates (Figure 7.4). Showing just the population means supports this finding, the Arctic populations group together high on both variables, with the hot climates low and the temperate populations intermediate (Figure 7.5).

Figure 7.4 : Ulna distal joint index against claviculo-radial index, by climate.

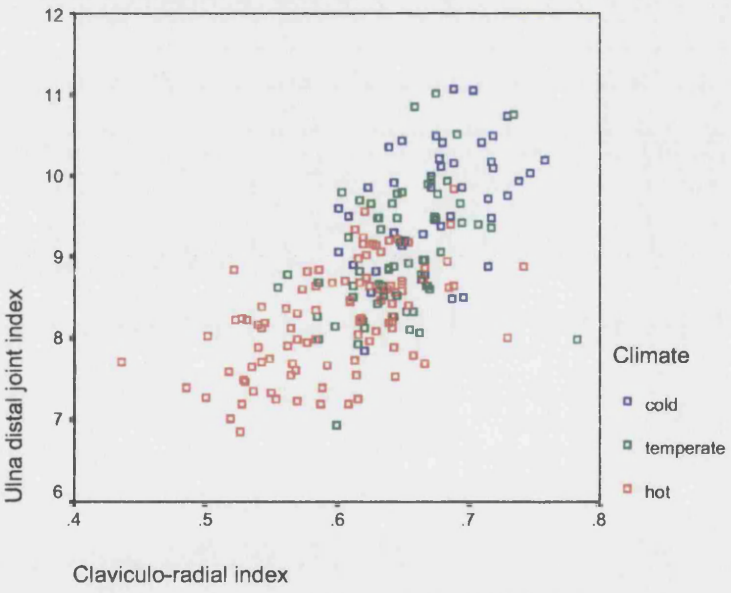
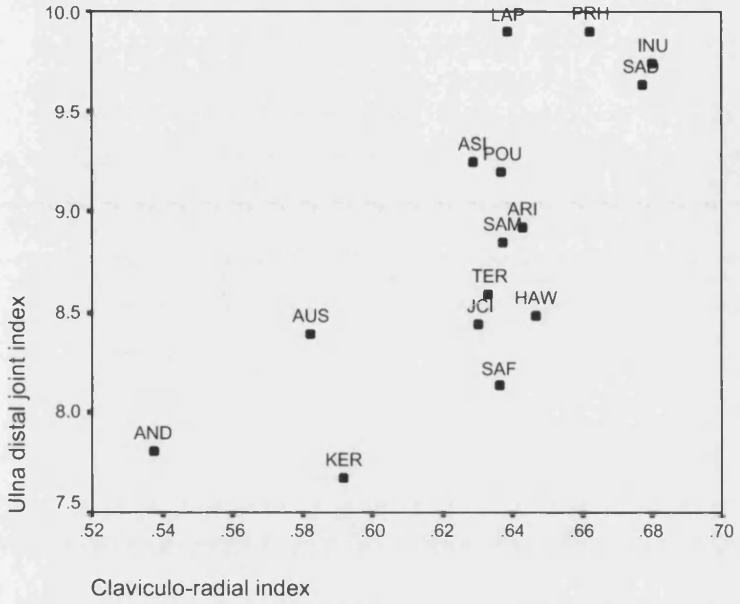


Figure 7.5 : Ulna distal joint index against claviculo-radial index, population means



Linear regressions against diaphyseal robusticity

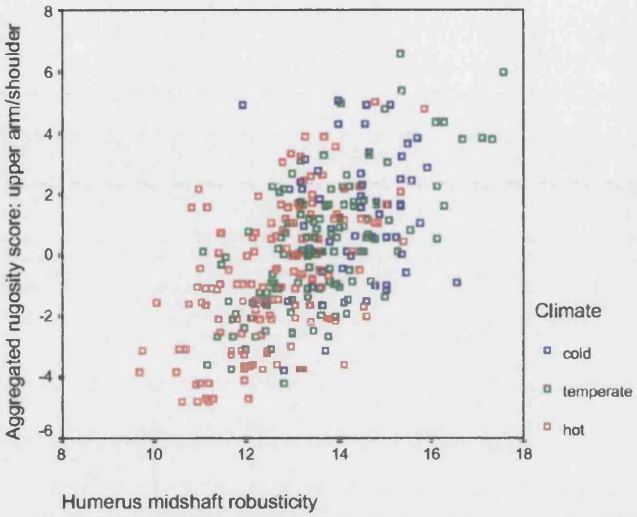
The aggregated score for forearm rugosity shows a significant relationship with all diaphyseal robusticity indices (Table 7.4). The aggregated scores for leg rugosity, upper arm and shoulder rugosity and upper body wear also show several significant relationships with diaphyseal robusticity, but not all are significant. All relationships are weak in explanatory power, with the strongest being that between humerus midshaft robusticity and the aggregated score for upper arm and shoulder rugosity. In this skeletal region, a strong deltoid tuberosity could contribute both to a high rugosity score and expansion of the midshaft, enhancing this relationship. Plotted by climate, the cold and temperate populations have higher rugosity and robusticity in this area, while hot climate populations have both more gracile and smoother bones (Figure 7.6).

Table 7.4 : Least-squares linear regression statistics for postcranial rugosity on postcranial diaphyseal robusticity

Dependent variable	Independent variable	Intercept	Slope	Sig.	R squared
Aggregate 1 (Forearm rugosity)	TMSRI	-5.783	.407	.000 **	.045
	RMSRI	-7.613	.651	.000 **	.141
	UMSRI	-8.383	.699	.000 **	.175
	USBRI	-6.151	.415	.000 **	.119
	CMSRI	-4.740	.316	.000 **	.068
	HMSRI	-7.899	.599	.000 **	.132
	FMSRI	-9.045	.731	.000 **	.084
	FSTRI	-8.694	.675	.000 **	.116
Aggregate 2 (Leg rugosity)	TMSRI	-12.315	.863	.000 **	.135
	RMSRI	-2.670	.226	.060	.008
	UMSRI	-5.466	.454	.000 **	.042
	USBRI	-4.637	.311	.000 **	.038
	CMSRI	1.045	-.069	.409	.002
	HMSRI	-7.317	.551	.000 **	.066
	FMSRI	-10.733	.865	.000 **	.077
	FSTRI	-7.986	.618	.000 **	.061
Aggregate 3 (Upper arm/shoulder rugosity)	TMSRI	-8.440	.589	.000 **	.099
	RMSRI	-9.416	.797	.000 **	.209
	UMSRI	-10.664	.882	.000 **	.260
	USBRI	-8.053	.537	.000 **	.183
	CMSRI	-1.713	.110	.111	.005
	HMSRI	-12.948	.971	.000 **	.340
	FMSRI	-13.992	1.122	.000 **	.202
	FSTRI	-12.895	.993	.000 **	.254
Aggregate 4 (Wear rugosity)	TMSRI	-2.268	.159	.033*	.013
	RMSRI	-3.181	.271	.000 **	.054
	UMSRI	-3.091	.259	.005 **	.048
	USBRI	-1.961	.133	.006 **	.023
	CMSRI	-1.995	.132	.008 **	.023
	HMSRI	-2.252	.170	.002 **	.021
	FMSRI	-3.680	.296	.001 **	.030
	FSTRI	-3.173	.245	.002 **	.033

* = $p < .05$, ** = $p < .01$

Figure 7.6 : Aggregated rugosity for the upper arm and shoulder against humerus midshaft robusticity, by climate



Linear regressions against epiphyseal robusticity

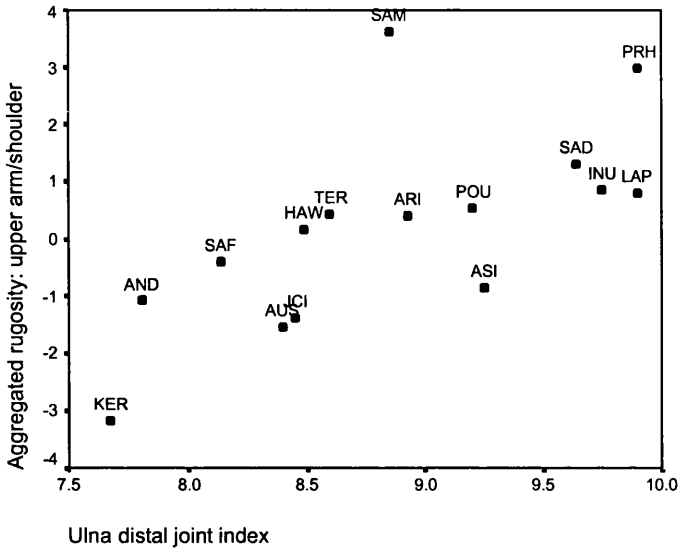
The aggregated rugosity scores all show significant relationships with the epiphyseal robusticity indices, but the relationships are again only weakly explanatory (Table 7.5). The strongest relationship is that between ulna distal joint index and the aggregated score for upper arm and shoulder rugosity. This suggests a link between arm rugosity and wrist activity as assessed through the distal ulnar epiphysis. Plotted by population means, the populations scoring high on both include the cold climate populations and the South American and Prince Rupert Harbour temperate groups (Figure 7.7). These groups share intense activity patterns involving either coastal rowing or, in the case of the Lapps, livestock herding.

Table 7.5 : Least-squares linear regression statistics for postcranial rugosity on postcranial epiphyseal robusticity

Dependent variable	Independent variable	Intercept	Slope	Sig.	R squared
Aggregate 1 (forearm rugosity)	TPJI	-5.045	.240	.006 **	.024
	FPJI	-8.857	.863	.000 **	.077
	FDJI	-6.093	.369	.001**	.029
	HPJI	-8.427	.598	.000 **	.063
	HDJI	-8.323	.435	.000 **	.077
	RPJI	-7.909	.818	.000 **	.086
	UDJI	-4.827	.544	.000 **	.055
Aggregate 2 (leg rugosity)	TPJI	-5.647	.278	.008 **	.020
	FPJI	-4.346	.422	.039 *	.010
	FDJI	-5.520	.333	.016 *	.015
	HPJI	-5.624	.397	.013 *	.016
	HDJI	5.549	.289	.005 **	.020
	RPJI	-4.199	.422	.022 *	.013
	UDJI	-4.760	.622	.001 **	.048
Aggregate 3 (upper arm/shoulder rugosity)	TPJI	-12.249	.578	.000 **	.149
	FPJI	-14.246	1.378	.000 **	.197
	FDJI	-12.990	.772	.000 **	.138
	HPJI	-12.915	.909	.000 **	.143
	HDJI	-8.158	.421	.000 **	.075
	RPJI	-10.246	1.051	.000 **	.149
	UDJI	-12.554	1.425	.000 **	.306
Aggregate 4 (wear rugosity)	TPJI	-2.724	.130	.040 *	.013
	FPJI	-2.573	.248	.033 *	.012
	FDJI	-3.909	.231	.005 **	.025
	HPJI	-2.420	.171	.056 *	.009
	HDJI	-2.781	.144	.017 *	.016
	RPJI	-4.447	.458	.000 **	.061
	UDJI	-3.100	.350	.003 **	.040

* = $p < .05$, ** = $p < .01$

Figure 7.7 : Upper arm and shoulder rugosity against ulna distal joint index



Comparing postcranial diaphyseal and epiphyseal robusticity

The final analysis within the postcranial data is to investigate the relationship between diaphyseal and epiphyseal robusticity at each of the long bones. This follows a similar analysis in Pearson (2000), in his method of regressing diaphyseal robusticity against epiphyseal robusticity for the same limb element (Table 7.6).

All the diaphyseal and epiphyseal robusticity indices show significant relationships with one another (Table 7.6). For most limb elements, the R squared values indicate low to moderate explanatory power. The regressions of femur sub-trochanter robusticity on proximal and distal epiphyseal robusticity are especially low in explanatory power. The femur sub-trochanter region has been shown in previous chapters to be sensitive to lifestyle differences where other regions of the femur are

not. The regression of humerus midshaft robusticity on humerus distal epiphyseal robusticity is also of low explanatory power, although the regression of humerus midshaft robusticity on humerus proximal epiphyseal robusticity is stronger.

Table 7.6 : Least-squares linear regression statistics for diaphyseal robusticity on epiphyseal robusticity

Dependent variable	Independent variable	Intercept	Slope	Sig.	R squared
FMSRI	FPJI	3.912	.826	.000 **	.46
FMSRI	FDJI	5.193	.434	.000 **	.49
FSTRI	FPJI	1.824	1.079	.000 **	.28
FSTRI	FDJI	4.779	.491	.000 **	.22
TMSRI	TPJI	3.533	.511	.000 **	.40
HMSRI	HPJI	.155	.926	.000 **	.40
HMSRI	HDJI	7.074	.322	.000 **	.12
UMSRI	UDJI	3.145	1.018	.000 **	.49
USBRI	UDJI	1.976	1.499	.000 **	.52
RMSRI	RPJI	.520	1.156	.000 **	.56

* = p < .05, ** = p < .01

That there should be association between diaphyseal and epiphyseal robusticity is not surprising, since all parts of the skeleton are subject to stress in relation to individual body size and activities, and the limbs operate as functional units. Residuals are calculated from the linear regression line, and used to investigate what Pearson (2000) terms the 'residual strength', or the relative robusticity of the diaphysis over what is expected from the epiphyseal robusticity. Residuals over 0 indicate a more robust diaphysis than would be expected, given the robusticity of the epiphysis. Since epiphyses are thought to be less responsive to activity than diaphyses, and to track body mass more directly, residuals over 0 indicate elements that are robust for body size. The mean standardised residuals from each of the

above regressions are plotted by age, sex, lifestyle, climate and continent to indicate trends within the data set.

In the upper body, males have more residual strength in all their diaphyses than females (Figure 7.8 and Table 7.7).

Figure 7.8: Upper body standardised residuals, by sex

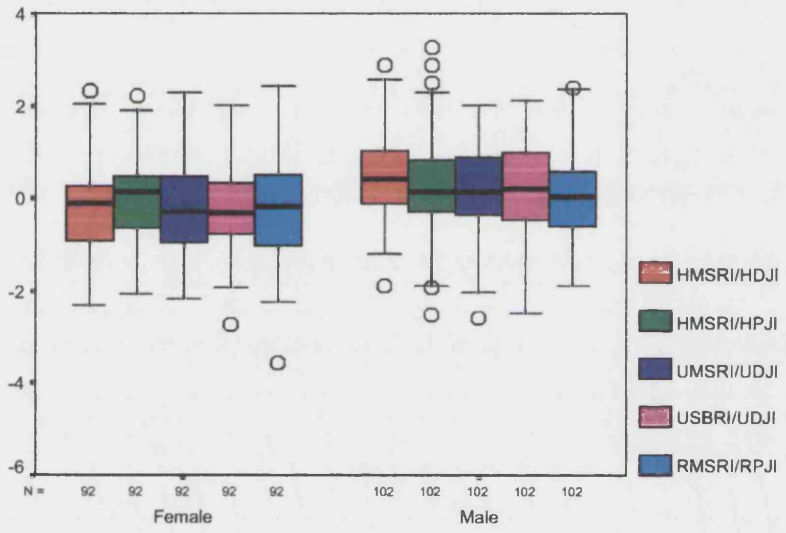


Table 7.7 T-test results for upper body standardised residuals, between sexes

		Levene test		T-test		
Regression		**F**	**Sig.**	**t**	**df**	**Sig. (2-tailed)**
HMSRI/HDJI	Equal variance assumed	1.535	.216	-4.340	333	.000 **
HMSRI/HPJI	Equal variance assumed	.061	.804	-2.154	335	.032 *
UMSRI/UDJI	Equal variance assumed	.732	.393	-2.601	199	.010 *
USBRI/UDJI	Equal variance assumed	3.767	.054	-3.284	199	.001 **
RMSRI/RPJI	Equal variance assumed	1.020	.313	-2.005	326	.046 *

* = p < .05, ** = p < .01

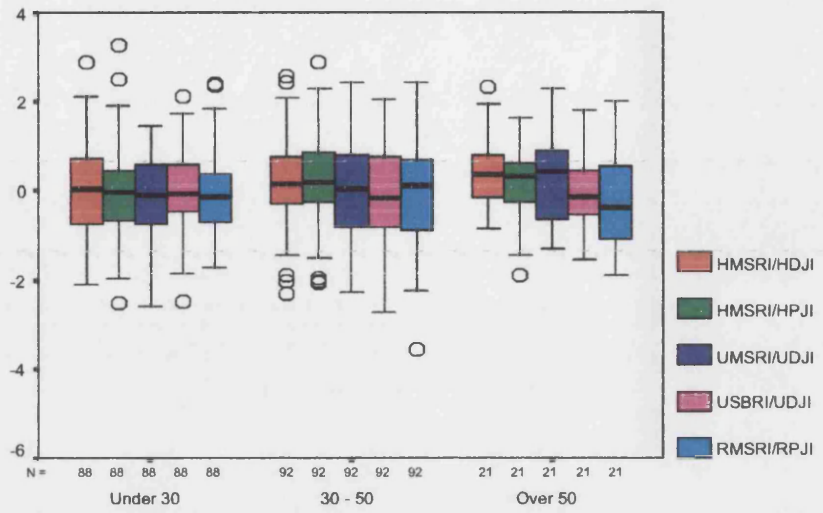
By age, the residual strength of the diaphyses compared with the epiphyses is not significant in any cases (Table 7.8 and Figure 7.9). By climate, residual strength in the upper body tends to increase with decreasing temperatures (Figure 7.10). However, this is only significant for some of the upper body elements (Table 7.9). The ulnar residuals are not significantly different between hot and temperate climates, and neither the two ulnar residuals nor the radius residual differs significantly between temperate and cold climates. Between hot and temperate climates, only the residual for ulna sub-brachial index against distal ulna joint index fails to achieve significance. However, the humerus residuals both show significant differences between all climatic categories.

Table 7.8 T-test for upper body standardised residuals, between age categories

Regression		Levene test F	Sig.	T-test t	df	Sig. (2-tailed)
Young to middle age						
HMSRI/HDJI	Equal variances assumed	.563	.454	-2.116	297	.035
HMSRI/HPJI	Equal variances assumed	.001	.972	-1.648	299	.100
UMSRI/UDJI	Equal variances assumed	3.152	.077	-.509	184	.611
USBRI/UDJI	Equal variances not assumed	6.407	.012	.431	176.528	.667
RMSRI/RPJI	Equal variances assumed	1.398	.238	.144	293	.885
Middle to older age						
HMSRI/HDJI	Equal variances assumed	.311	.578	-.006	183	.995
HMSRI/HPJI	Equal variances assumed	.304	.582	1.189	186	.236
UMSRI/UDJI	Equal variances assumed	.004	.948	-1.256	115	.212
USBRI/UDJI	Equal variances assumed	.354	.553	-.552	115	.582
RMSRI/RPJI	Equal variances assumed	.295	.588	-.195	180	.845
Young to older age						
HMSRI/HDJI	Equal variances assumed	.002	.965	-1.405	202	.161
HMSRI/HPJI	Equal variances assumed	.329	.567	.084	203	.933
UMSRI/UDJI	Equal variances assumed	1.463	.229	-1.861	111	.065
USBRI/UDJI	Equal variances assumed	1.038	.311	-.377	111	.707
RMSRI/RPJI	Equal variances assumed	1.960	.163	-.113	197	.911

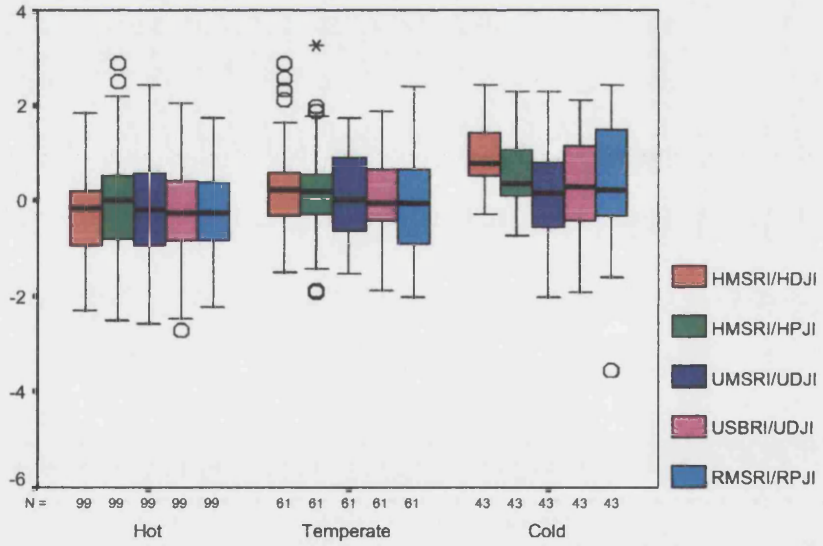
* = $p < .05$, ** = $p < .01$

Figure 7.9: Upper body standardised residuals, by age



Age Category

Figure 7.10: Upper body standardised residuals, by climate



CLIMATE

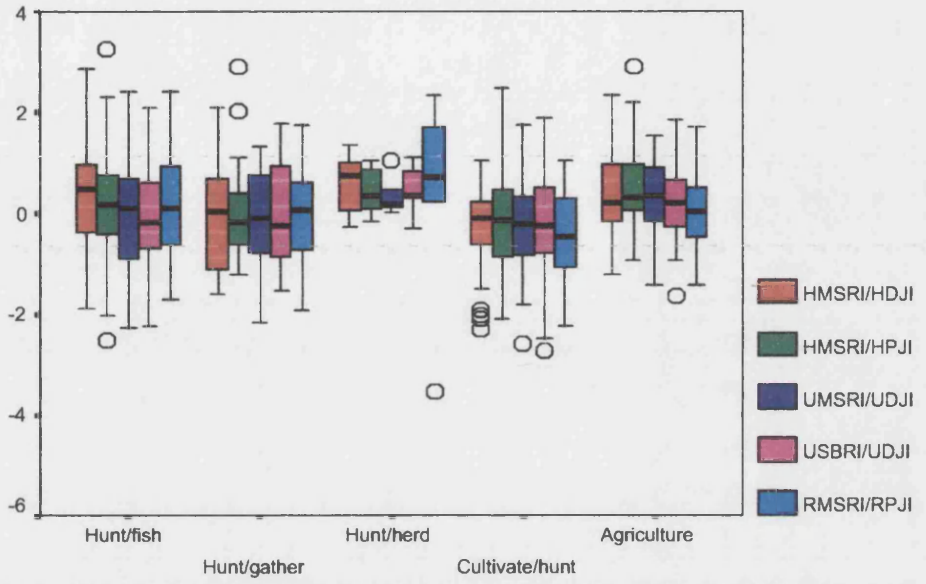
Table 7.9 T-test for upper body standardised residuals, between climates

Regression		Levene test F	Levene test Sig.	T-test t	T-test df	T-test Sig. (2-tailed)
Hot / Temp						
HMSRI/HDJI	Equal variances assumed	.397	.529	-5.896	291	.000 **
HMSRI/HPJI	Equal variances assumed	4.777	.030	-2.326	278	.021 *
UMSRI/UDJI	Equal variances assumed	.952	.331	-1.441	163	.151
USBRI/UDJI	Equal variances assumed	.689	.408	-1.724	163	.087
RMSRI/RPJI	Equal variances assumed	.323	.570	-2.846	283	.005 **
Temp / Cold						
HMSRI/HDJI	Equal variances assumed	2.656	.105	-4.706	207	.000 **
HMSRI/HPJI	Equal variances assumed	.164	.686	-3.198	213	.002 **
UMSRI/UDJI	Equal variances assumed	.797	.374	-.704	106	.483
USBRI/UDJI	Equal variances assumed	4.714	.032	-.933	79	.354
RMSRI/RPJI	Equal variances assumed	1.842	.176	-1.486	207	.139
Hot / Cold						
HMSRI/HDJI	Equal variances assumed	5.287	.023	-10.530	142	.000 **
HMSRI/HPJI	Equal variances assumed	4.398	.037	-5.064	163	.000 **
UMSRI/UDJI	Equal variances assumed	.001	.979	-1.918	145	.057
USBRI/UDJI	Equal variances assumed	2.164	.143	-2.423	145	.017 *
RMSRI/RPJI	Equal variances assumed	3.601	.059	-3.691	202	.000 **

* = $p < .05$, ** = $p < .01$

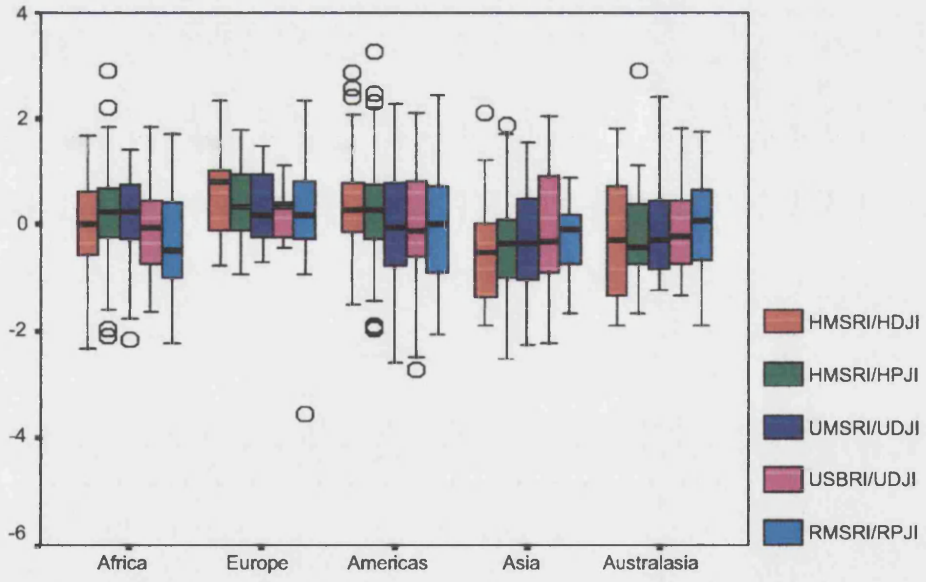
By lifestyle, the upper body shows consistent response to subsistence strategy (Figure 7.11). In particular, the hunt/herd groups show high residual strength in the diaphyses, while cultivate/hunt groups are less robust at the diaphyses than their body mass (via epiphyseal robusticity) would suggest. There are consistent patterns by continent as well, in that continents characterised by high residual strength in one upper body element have high residual strength in the other elements (Figure 7.12). The European and American continents contain individuals with high residual strength, while Asian and Australasian populations tend to have low residual strength.

Figure 7.11 : Upper body standardised residuals, by lifestyle



Lifestyle

Figure 7.12: Upper body standardised residuals, by continent



Continent

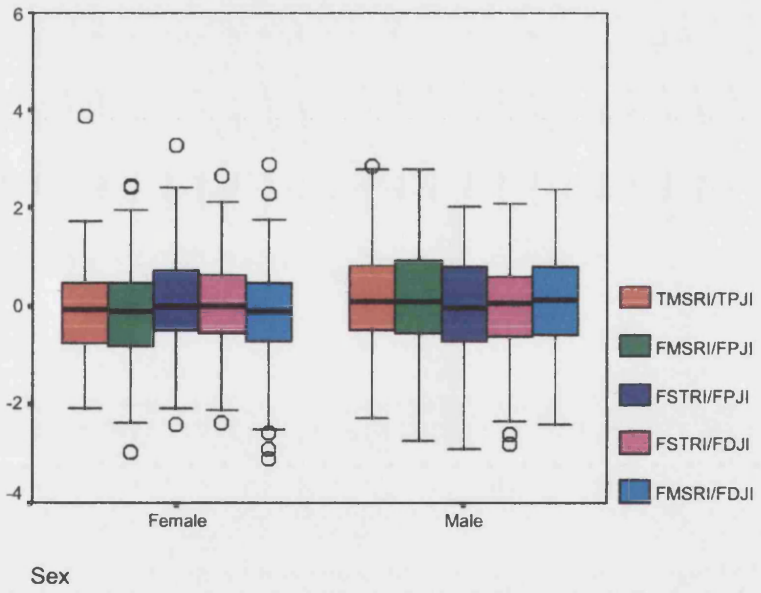
The lower body residuals behave in a slightly different way to the upper body residuals in respect of the categories used in these analyses. Males have more residual strength than females only for the tibia and femur midshaft, when regressed against proximal joint robusticity (Table 7.10). The male means are not significantly higher than those of females in the other regressions (Figure 7.13).

Table 7.10 T-test for lower body standardised residuals, between sexes

Regression	Levene test	F	Sig.	T-test t	df	Sig. (2-tailed)
TMSRI/TPJI	Equal variances assumed	.249	.618	-2.940	281	.004 **
FMSRI/FPJI	Equal variances assumed	.288	.592	-2.185	337	.030 *
FSTRI/FPJI	Equal variances assumed	.622	.431	1.544	337	.124
FSTRI/FDJI	Equal variances assumed	.441	.507	.609	321	.543
FMSRI/FDJI	Equal variances assumed	.120	.729	-1.763	321	.079

* = p < .05, ** = p < .01

Figure 7.13: Lower body standardised residuals, by sex



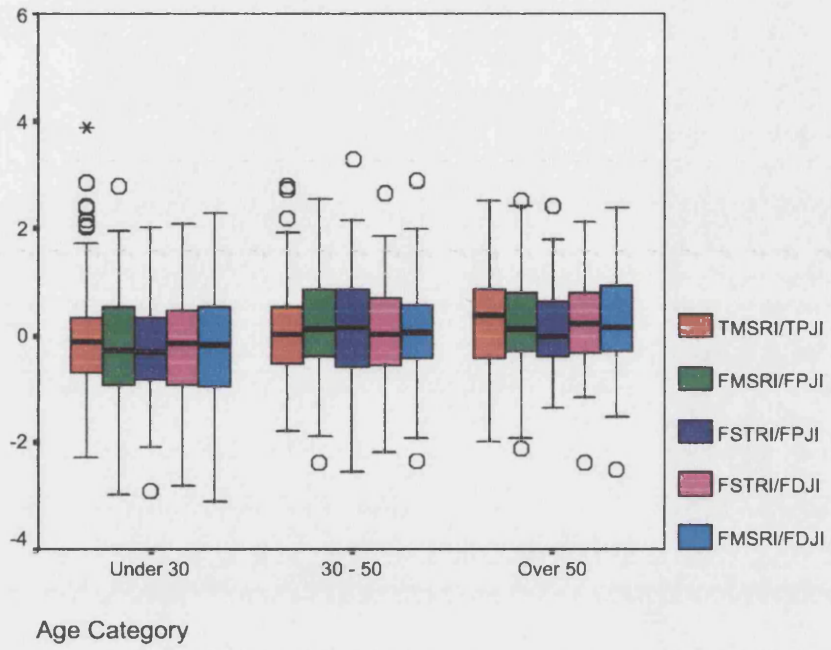
Femoral residual strength increases significantly between young and middle adulthood, however it is assessed but tibia residual strength shows no significant increase (Table 7.11). From middle to older adulthood, there are no significant differences in residual strength in the lower body, and comparing the oldest and youngest age categories, only three of the femoral residuals show significant difference(Figure 7.13).

Table 7.11 T-test for lower body standardised residuals, between age categories

Regression		Levene test F	Sig.	T-test t	df	Sig. (2-tailed)
Younger to middle age						
TMSRI/TPJI	Equal variances assumed	2.158	.143	-1.029	254	.304
FMSRI/FPJI	Equal variances assumed	2.757	.098	-3.006	301	.003 **
FSTRI/FPJI	Equal variances assumed	.274	.601	-2.985	301	.003 **
FSTRI/FDJI	Equal variances assumed	1.982	.160	-2.688	288	.008 **
FMSRI/FDJI	Equal variances not assumed	7.959	.005	-2.860	281.312	.005 **
Middle to older age						
TMSRI/TPJI	Equal variances assumed	1.360	.245	-1.286	155	.201
FMSRI/FPJI	Equal variances assumed	.520	.472	.023	189	.982
FSTRI/FPJI	Equal variances assumed	.240	.625	-.641	189	.522
FSTRI/FDJI	Equal variances assumed	.061	.806	-1.131	182	.260
FMSRI/FDJI	Equal variances assumed	3.787	.053	-.818	182	.414
Younger to older age						
TMSRI/TPJI	Equal variances assumed	.003	.957	-1.784	171	.076
FMSRI/FPJI	Equal variances assumed	.157	.692	-1.933	202	.055
FSTRI/FPJI	Equal variances assumed	.026	.872	-2.770	202	.006 **
FSTRI/FDJI	Equal variances assumed	.495	.482	-2.837	192	.005 **
FMSRI/FDJI	Equal variances assumed	.003	.956	-2.467	192	.014 *

* = p < .05, ** = p < .01

Figure 7.14: Lower body standardised residuals, by age



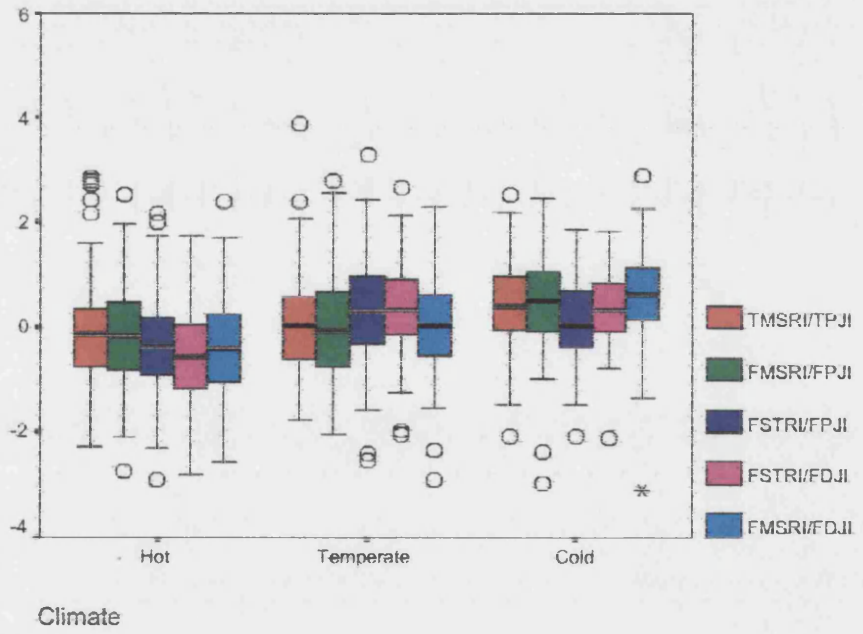
Residual strength in the lower body generally increases with decreasing temperatures (Figure 7.14). In the femur, residual strength is generally significantly lower in hot climates than in temperate or cold climates (Table 7.12). The exception is when femur sub-trochanter robusticity is regressed against the proximal femur joint index. The tibia residual strength is only significantly different between temperate and cold climates.

Table 7.12 T-tests for lower body standardised residuals, between climates

Regression		Levene test F	Sig.	T-test t	df	Sig. (2-tailed)
	Hot /Temperate					
TMSRI/TPJI	Equal variances assumed	.003	.955	-1.256	248	.210
FMSRI/FPJI	Equal variances assumed	.507	.477	-1.907	295	.057
FSTRI/FPJI	Equal variances assumed	.436	.509	-6.646	295	.000 **
FSTRI/FDJI	Equal variances assumed	2.439	.119	-9.861	279	.000 **
FMSRI/FDJI	Equal variances assumed	1.593	.208	-5.437	279	.000 **
	Temperate / Cold					
TMSRI/TPJI	Equal variances assumed	.195	.660	-2.042	164	.043 *
FMSRI/FPJI	Equal variances assumed	.989	.321	-2.457	210	.015 *
FSTRI/FPJI	Equal variances assumed	.490	.485	1.533	210	.127
FSTRI/FDJI	Equal variances assumed	.578	.448	-.638	201	.524
FMSRI/FDJI	Equal variances assumed	.723	.396	-3.978	201	.000 **
Hot / Cold						
TMSRI/TPJI	Equal variances assumed	.153	.696	-3.036	184	.003
FMSRI/FPJI	Equal variances assumed	.224	.637	-3.772	207	.000 **
FSTRI/FPJI	Equal variances assumed	.034	.853	-3.783	207	.000 **
FSTRI/FDJI	Equal variances assumed	3.677	.057	-8.070	192	.000 **
FMSRI/FDJI	Equal variances assumed	.003	.957	-7.574	192	.000 **

* = p < .05, ** = p < .01

Figure 7.15: Lower body standardised residuals, by climate



By lifestyle, the patterns of residual strength in the lower body are inconsistent (Figure 7.16). The femur regions and tibia midshaft respond in different ways to lifestyle. The tibia midshaft is especially strong relative to proximal tibia robusticity among hunt/gather and cultivate/hunt groups, while the hunt/herd peoples have less strong tibiae than their epiphyses (body mass) would suggest. Relative mobility levels between subsistence strategies could be the key here. Hunt/gather and cultivate/hunt peoples may need much larger diurnal walking distances, whereas people with herd and riding animals may not be exposed to so much walking.

The patterns of residual strength tend to be more consistent by continent than by lifestyle (Figure 7.17). The exception is the Australasian tibia, which is very much stronger than expected from epiphyseal robusticity. The femur midshaft and sub-trochanter diaphyses appear more or less strong depending on which epiphysis they have been regressed against. This is examined in more detail below.

Boxplots for all of the standardised residuals illustrate the high level of overlap between categories, and hence a low probability of being able to determine category membership from robusticity residuals.

Figure 7.16: Lower body standardised residuals, by lifestyle

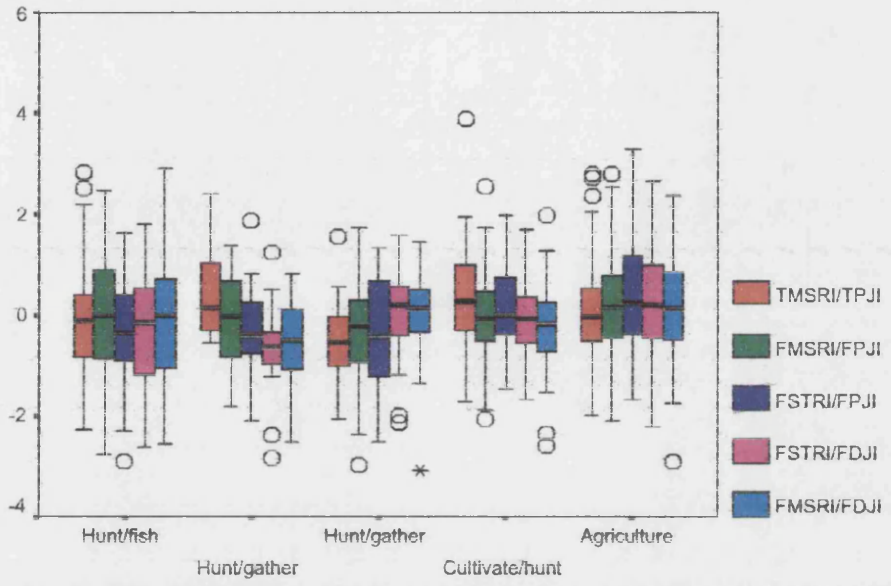
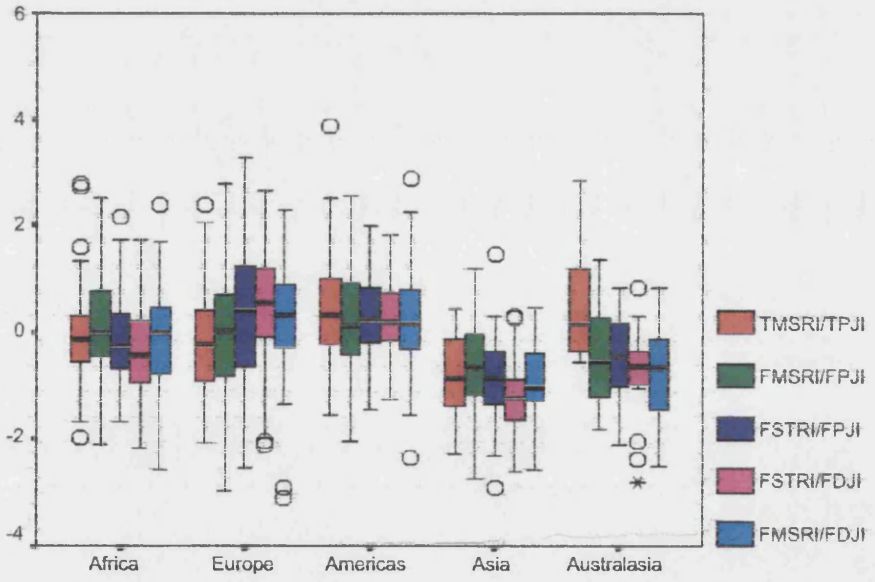


Figure 7.17: Lower body standardised residuals, by continent



Since Pearson used only male means, and did not investigate age, sex or continent as categorical variables, it is not straightforward to compare results. However, Pearson found that cold climate individuals tend to have more robust diaphyses and epiphyses than hot climate individuals. This is generally supported by the plots using only population means, although the linear regression equations using the whole data set are more ambiguous. If the regression equations are obtained for the mean values only, the r-squared value for the equations fall closer to those reported by Pearson.

With this data set, cold climate individuals tend to have both higher epiphyseal and diaphyseal robusticity, but the residual strength, or position of populations either side of the regression line is unrelated to climate. A selection of possible scatter plots are shown, (Figures 7.18, 7.19 and 7.20) since the remainder show the same patterns. In all of these, hot, temperate and cold climate populations are found on both sides of the regression line.

Figure 7.18: Ulna midshaft robusticity against ulna distal joint index, population means r^2 = .91, slope = 1.133, intercept = 2.148

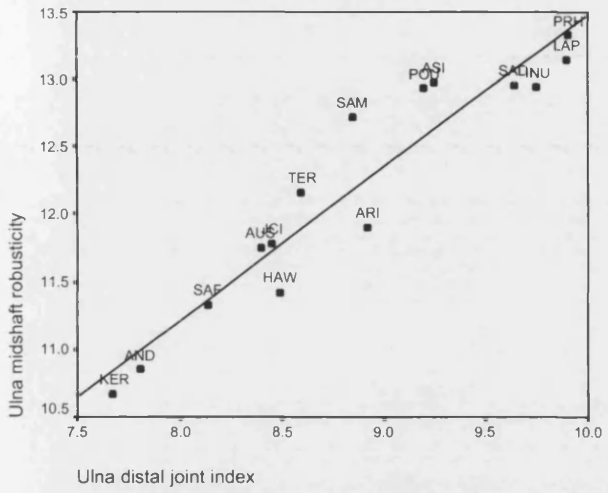


Figure 7.19 : Ulna sub-brachial robusticity index against ulna distal joint index, population means r^2 = .95, slope = 1.746, intercept = -.283

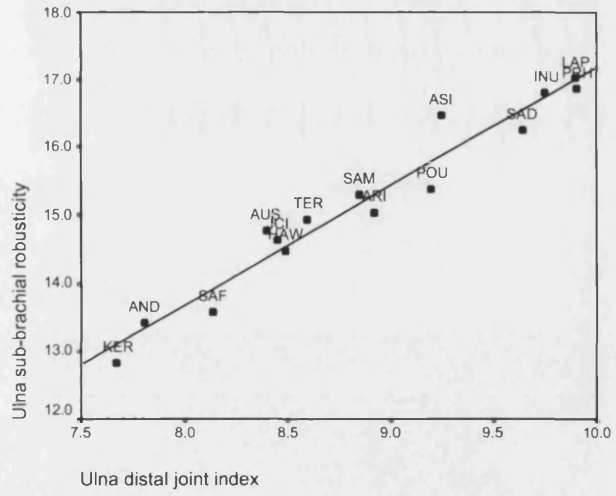
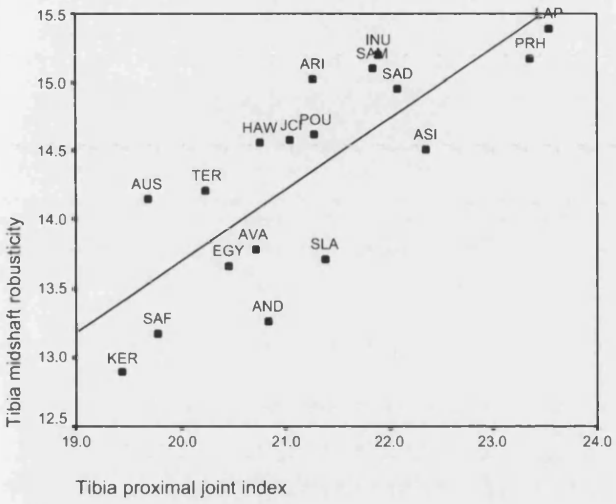
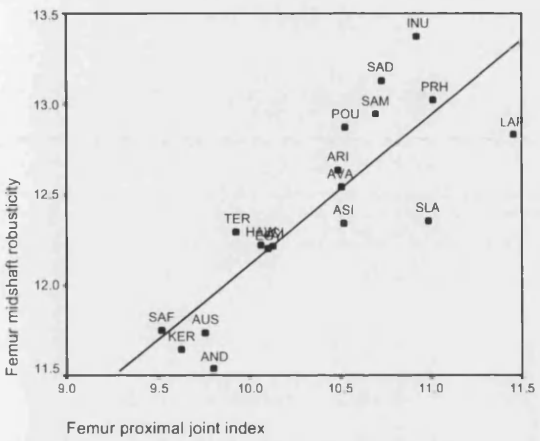


Figure 7.20 :Tibia midshaft robusticity against tibia proximal joint index, population means r^2 = .60, slope = .515, intercept = 3.403



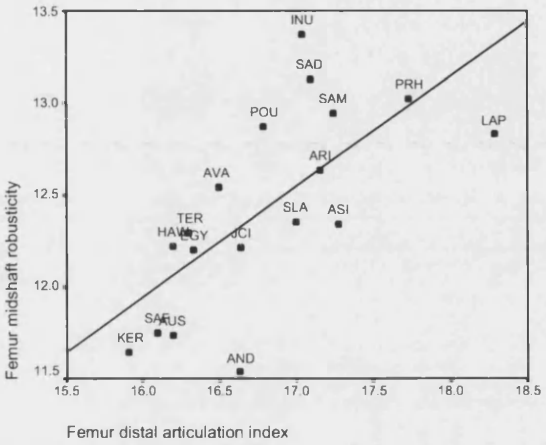
When the midshaft robusticity of the femur and humerus are plotted against the distal epiphysis index, there is considerably more unexplained variance, compared with the plot against the proximal joint index (Figures 7.21 and 7.22). For the femur, the relative positions of populations to one another remains similar, but the distance from the regression line is greater when the distal epiphysis index is used. For the humerus, the pattern of populations around the regression line is quite different when the distal joint index is used, and some populations that appeared to have relatively strong diaphyses relative to the humeral head index, appear more gracile relative to distal humerus index.

Figure 7.21 :a. Femur midshaft robusticity index against femur proximal joint index , and b. against femur distal joint index, population means



a.

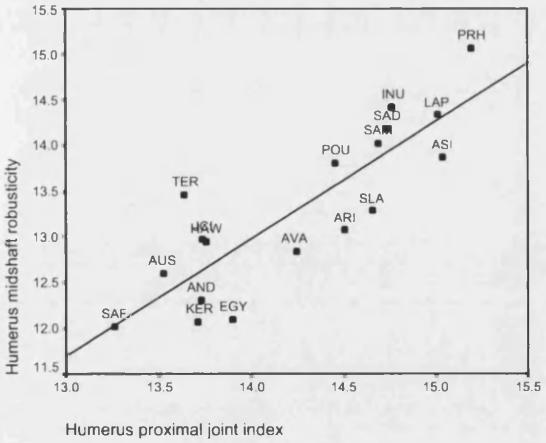
r^2 = .69, slope = .827, intercept = 3.844



b.

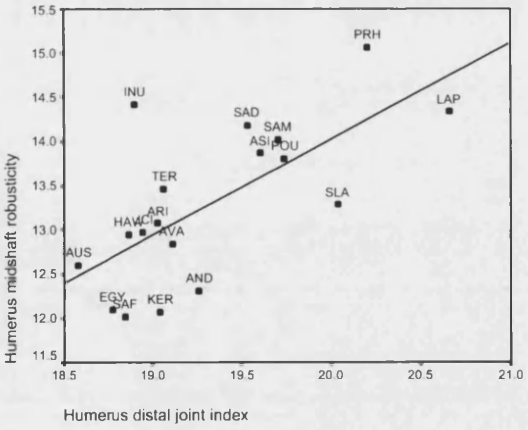
r^2 = .47, slope = .599, intercept = 2.355

Figure 7.22 : a. Humerus midshaft robusticity against humerus proximal joint index, and b. against humerus distal joint index, population means



a.

r^2 = .73, slope = 1.283, intercept = -4.980



b.

r^2 = .46, slope = 1.085, intercept = -7.672

Reflecting on the results from Chapter 3, epiphyseal robusticity indices are not solely reflections of body mass, but are themselves affected by sex and lifestyle, often differentially at each end of an element. Given this, and the fact that midshaft robusticity has a more direct association with proximal joint indices than distal joint epiphyses, it is not clear whether calculating residual strength from the proximal joint index is the most appropriate method. The distal joint indices may reflect activity differences better than the proximal joint indices, and this be more useful in interpreting residual strength.

Comparisons between cranial and postcranial variables

Linear regressions of cranial size and shape on selected postcranial variables

The aim here is to see whether cranial size and shape are associated with postcranial robusticity or body shape. Cranial size is represented by the cranial module, and cranial shape by the cranial index (equivalent to the cephalic index). They are regressed against diaphyseal and epiphyseal robusticity, represented by the humeral and femoral midshaft robusticity and proximal joint indices (HMSRI, FMSRI), and against the three body shape indices used above (brachial, crural, claviculo-radial). Formulae for all these indices are listed in Chapter 2.

Table 7.13: Least-squares linear regression statistics for cranial size and shape on diaphyseal robusticity, epiphyseal robusticity and body shape indices

Dependent variable	Independent variable	Intercept	Slope	Sig.	R squared
Cranial module	FMSRI	119.543	2.340	.000 **	.13
Cranial module	FPJI	118.896	2.880	.000 **	.11
Cranial module	HMSRI	126.462	1.677	.000 **	.14
Cranial module	HPJI	118.033	2.166	.000 **	.11
Cranial module	Brachial index	152.690	-5.388	.523	-.002
Cranial module	Crural index	169.382	-25.846	.004 **	.03
Cranial module	Claviculoradial index	135.428	21.05	.001 **	.04
Cranial shape index	FMSRI	141.257	8.183	.000 **	.13
Cranial shape index	FPJI	133.504	10.622	.000 **	.14
Cranial shape index	HMSRI	168.799	5.622	.000 **	.13
Cranial shape index	HPJI	.782	-.001	.000 **	.12
Cranial shape index	Brachial index	247.562	-5.456	.844	-.003
Cranial shape index	Crural index	318.337	-93.553	.002 **	.03
Cranial shape index	Claviculoradial index	205.756	59.788	.007 **	.02

* = p < .05, ** = p < .01

Several of these regressions show significant relationships between cranial size and shape (index and module) and postcranial robusticity and body shape (Table 7.13). The only exception is brachial index, which shows no significant relationship with cranial size or shape. The r-squared values indicate that very low levels of cranial variability are explained by postcranial variability, especially where cranial size and shape are regressed against the body shape indices. When regressed against diaphyseal and epiphyseal robusticity, the explanatory power of the equations is somewhat better, but still poor. Represented on scatter plots, these weak relationships show that while postcranial variables are influenced by climate, cranial module and shape are not. Two scatter plots are shown, (Figures 7.23 and 7.24) as

examples of the general trends. Scattered by other categories, such as lifestyle and continent, or against body shape indices, there are no interesting patterns.

Figure 7.23: Cranial shape index against humerus midshaft robusticity, by climate.

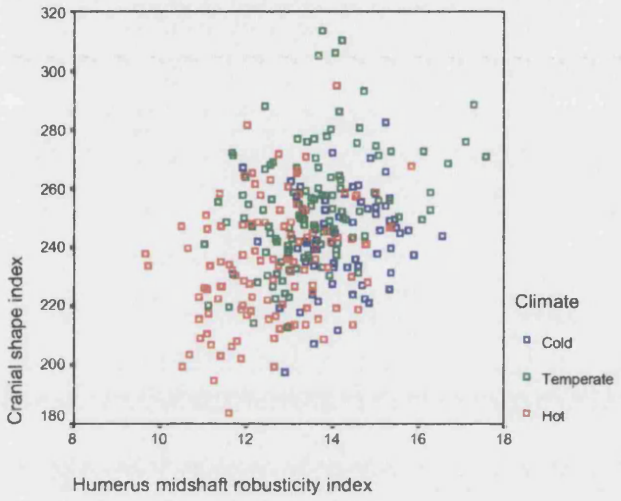
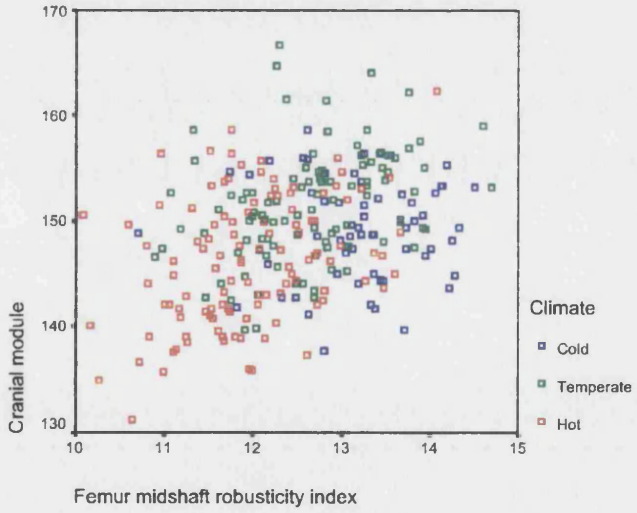


Figure 7.24: Cranial module against femur midshaft robusticity, by climate.



Linear regressions of cranial robusticity and rugosity against postcranial robusticity

There are no significant relationships between cranial and postcranial robusticity indices (Table 7.14). However, aggregated cranial rugosity does show significant relationships with diaphyseal and epiphyseal robusticity.

Table 7.14: Least-squares linear regression statistics for cranial robusticity and rugosity on selected diaphyseal and epiphyseal robusticity variables

Dependent variable	Independent variable	Intercept	Slope	Sig.	R^2
Gnathic index	FPJI	105.838	-.812	.510	.01
Zygomatic breadth index	FPJI	.691	.019	.332	.09
Nasal height index	FPJI	.386	.006	.448	.02
Malar height index	FPJI	.188	.005	.314	.02
Forehead breadth index	FPJI	.737	.003	.073	.001
Aggregated cranial rugosity	FPJI	-.850	.064	.011 *	.016
Gnathic index	FMSRI	106.315	-.709	.684	.02
Zygomatic breadth index	FMSRI	.650	.019	.660	.15
Nasal height index	FMSRI	.335	.009	.427	.07
Malar height index	FMSRI	.174	.005	.568	.03
Forehead breadth index	FMSRI	.790	-.002	.531	-.001
Aggregated cranial rugosity	FMSRI	-.993	.079	.002 **	.03
Gnathic index	HPJI	118.033	2.166	.405	-.001
Zygomatic breadth index	HPJI	100.912	-2.46	.966	.06
Nasal height index	HPJI	.716	.012	.912	.02
Malar height index	HPJI	.381	.005	.118	.01
Forehead breadth index	HPJI	.102	.003	.084	-.003
Aggregated cranial rugosity	HPJI	-.959	.068	.008 **	.019
Gnathic index	HMSRI	98.976	-.117	.619	-.003
Zygomatic breadth index	HMSRI	.710	.013	.318	.15
Nasal height index	HMSRI	.383	.005	.993	.04
Malar height index	HMSRI	.175	.005	.299	.05
Forehead breadth index	HMSRI	.774	-.005	.700	-.003
Aggregated cranial rugosity	HMSRI	-.852	.064	.000 **	.037

* = $p < .05$, ** = $p < .01$

Linear regressions of cranial rugosity and robusticity against postcranial rugosity

There are few significant relationships between cranial rugosity or robusticity and postcranial rugosity, as assessed through indices and aggregated rugosity scores (Table 7.15). Aggregated cranial rugosity and some of the cranial robusticity indices correlate significantly with the four postcranial rugosity aggregate scores.

Table 7.15 : Least-squares linear regression statistics for cranial robusticity and rugosity on postcranial rugosity

Dependent variable	Independent variable	Intercept	Slope	Sig.	R^2
Gnathic index	Aggregate 1	97.223	-.101	.462	.002
Zygomatic breadth index		.884	.004	.359	.004
Nasal height index		.452	.008	.139	.010
Malar height index		.240	-.025	.050	.017
Forehead breadth index		.876	.002	.514	.000
Aggregated cranial rugosity		-.002	.043	.000 **	.048
Gnathic index	Aggregate 2	97.497	-.193	.073	.014
Zygomatic breadth index		.878	.000	.584	.001
Nasal height index		.445	.001	.235	.006
Malar height index		.239	-.002	.013 *	.026
Forehead breadth index		.772	.000	.765	.000
Aggregated cranial rugosity		-.004	.003	.000 **	.047
Gnathic index	Aggregate 3	97.512	.086	.518	.002
Zygomatic breadth index		.879	.000	.501	.002
Nasal height index		.446	-.000	.933	.000
Malar height index		.239	-.002	.015 *	.025
Forehead breadth index		.772	.002	.012 *	.026
Aggregated cranial rugosity		-.031	.032	.002 **	.031
Gnathic index	Aggregate 4	97.562	.346	.105	.013
Zygomatic breadth index		.881	.002	.457	.003
Nasal height index		.446	.000	.804	.000
Malar height index		.240	.001	.479	002
Forehead breadth index		.772	.000	.664	.001
Aggregated cranial rugosity		-.003	.045	.008 *	.026

* = $p < .05$, ** = $p < .01$

Summary

Epiphyseal and diaphyseal robusticity are significantly related, and residual strength from the regressions has been investigated. Both kinds of postcranial robusticity are associated with colder climates, and this supports the essence of Pearson's findings, although the strength of the relationships reported here are weaker than those reported by Pearson (2000).

Investigation of relationships between cranial and postcranial variables demonstrate some significant relationships, but little explanatory power. Cranial and postcranial robusticity are not significantly related, neither are cranial robusticity and postcranial rugosity. Cranial and postcranial rugosity show weak but significant correlation, as do cranial rugosity and postcranial robusticity, postcranial rugosity and robusticity and cranial rugosity and robusticity.

Some significant correlation between these data types (cranial and postcranial, scored and metric) is to be expected, since human skeletons are integrated functional entities. The very weak nature of all the significant relationships except those between diaphyseal and epiphyseal robusticity indicates that the data types, while not entirely independent of one another, are accessing somewhat different underlying information about human skeletal diversity. There is, after all, a lot of unexplained variance in most of the relationships. The extent to which these data types differ, and the nature of the differences, is explored below through Discriminant Function Analysis.

Discriminant Function Analysis

Discriminant function analysis (DFA) was performed on each of the four data types (postcranial metric, postcranial score, cranial metric and cranial score), using the same number of variables in each case. The aim is to attempt to classify the sample into populations using each of the four kinds of data, and then compare the results to the known population. This will establish the degree to which each kind of data predicts group membership. DFA can also be used to evaluate the accuracy of classification, to investigate how many individuals are classified wrongly, and which groups are particularly susceptible to being mis-classified.

The analysis was performed on the same data set each time, which was selected to include only populations with a minimum number of 14 individuals. The data set for this analysis comprises 276 individuals, and no missing data. The number of individuals in each sample population needs to exceed the number of variables used in the DFA, otherwise overfitting is a likely problem. Populations removed on this basis include the Lapp, Japanese, Australian, Slavic and Polynesian populations. Groups removed because they are not homogenous include the Asian and South American groups (Table 7.16). Since there are twelve remaining populations in this restricted data set, the chance of obtaining a correct classification by chance would be one in twelve, or approximately 8%.

Table 7.16: Data for Discriminant Function Analysis

Population	Males	Females	Total (including unknown sex)
US Black	13	13	26
Andaman	9	7	21
Arikara	7	7	14
Avar	15	15	30
Egyptian	9	11	21
Hawikuh	11	10	21
Jersey County, Illinois	13	15	28
Inuit	15	19	34
Kerma	6	7	14
Poundbury	16	13	31
Prince Rupert Harbour	9	11	20
Sadlermiut	7	9	16

The DFA is designed factorially, not sequentially, but variables are entered stepwise in order to reduce the predictors in a statistically sensible way, with no bias from the researcher. The enter criterion for all four analyses is .15 to ensure entry of all important variables. There are no special problems posed by unequal sample sizes, because this is a one-way analysis. It is assumed, however that the samples are equally typical of their populations. This means that the assignment of individuals to populations in the classification phase of DFA is equal for each population, rather than weighted by the number of individuals in each population, and reduces the likelihood of fitting correctly by chance.

Some further reduction in classification accuracy is likely to stem from the fact that some of the more distinctive populations and groups in the original data set are excluded here. Variables that were selected on the basis of their descriptive powers

on the complete data set, may be less valuable on the restricted data set. However, to ensure a fair comparison between the four types of data, and the appropriate use of DFA, the use of a restricted data set is necessary.

Postcranial Metric Discriminant Function Analysis

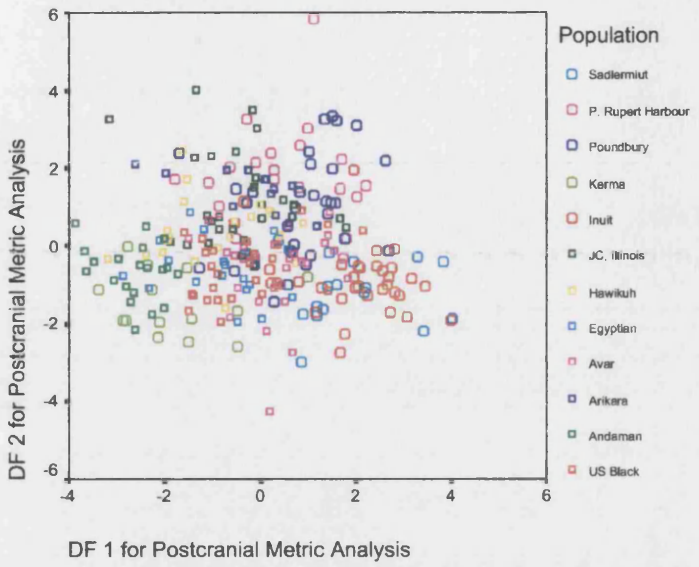
The eight variables used for postcranial metric DFA are femoral head diameter, femur midshaft medio-lateral diameter, femur sub-trochanter medio-lateral diameter, clavicle midshaft maximum diameter, ulna midshaft medio-lateral diameter, ulna sub-brachial medio-lateral diameter, radius functional length, and tibia functional length. The first eight canonical discriminant functions were used, but 95.1% of the cumulative variance is explained by the first four functions (Table 7.17). All variables were entered stepwise on the basis of statistical importance, in descending order as presented in the table.

Table 7.17: Discriminant Function Summary for Postcranial Metric Analysis

Function	Eigenvalue	Largest absolute variable/function correlation	% of Variance	Cumulative %	Canonical Correlation
1	1.739		41.5	41.5	.797
2	1.092	FSTML	26.1	67.5	.723
3	.674	TFXL, RFXL, CMSMX, FMSML	16.1	83.6	.635
4	.487		11.6	95.2	.572
5	.119	USBML	2.8	98.1	.327
6	.056	FHDIA	1.3	99.4	.230
7	.021	UMSML	.5	99.9	.144
8	.004		.1	100.0	.062

Discriminant Functions (DF) one and two separate the populations well (Figure 7.25). No single variable is associated uniquely with DF 1, but the three femur variables, representing femoral head and two medio-lateral diameters, load on DF 1 with coefficients over .45. The two long bone lengths, for tibia and radius, load in a mild negative fashion on DF 1, which implies that this function represents body size as body mass, rather than stature. This is supported by the way that populations like the three Canadian populations score high on DF 1, while the Andaman, Kerma, Egyptian and Hawikuh score low. Discriminant Function 2 is associated strongly with femur sub-trochanter medio-lateral diameter, and no other variables contribute to this function with coefficients stronger than +/- .3. The Jersey County Illinois, Arikara and Prince Rupert Harbour populations are placed high on DF 2, while the rest fall in intermediate to low positions.

Figure 7.25: Discriminant Functions 1 and 2 for Postcranial Metric DFA



Discriminant Functions 3 and 4 are less successful at distinguishing the populations. Individuals are more scattered, and trends are harder to detect (Figure 7.26). However, graphed by lifestyle and sex instead, some separation is noted (Figures 7.27 and 7.28). Males score higher than females on DF 3, but not DF 4. This adds to the scatter of lifestyle categories, but they are nonetheless reasonably well defined. DF 3 particularly separates the agriculture and hunt/fish groups. This is the function with the long bone lengths associated strongly with it, and thus may be detecting stature differences between the sexes, as well as the generally low already noted among the hunt/fish people, who are represented by the Andaman and Canadian populations. The cultivate/hunt group are placed lower on DF 4 than the other lifestyle categories. DF 4 has no strongly associated variables, but clavicle and ulna diameters load over .45 on this function, suggesting that upper body bone thickness

is relevant here. Further Discriminant Functions produce no separation by any criteria.

Figure 7.26: Discriminant Functions 3 and 4 for Postcranial Metric DFA, by population

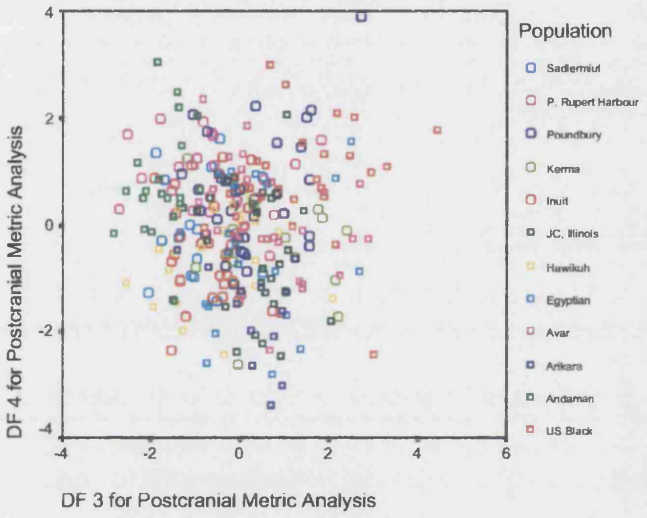


Figure 7.27: Discriminant Functions 3 and 4 for Postcranial Metric DFA, by lifestyle

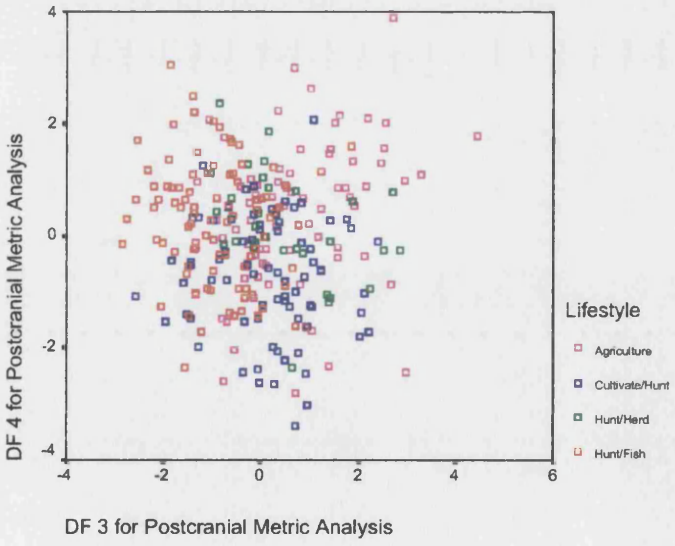
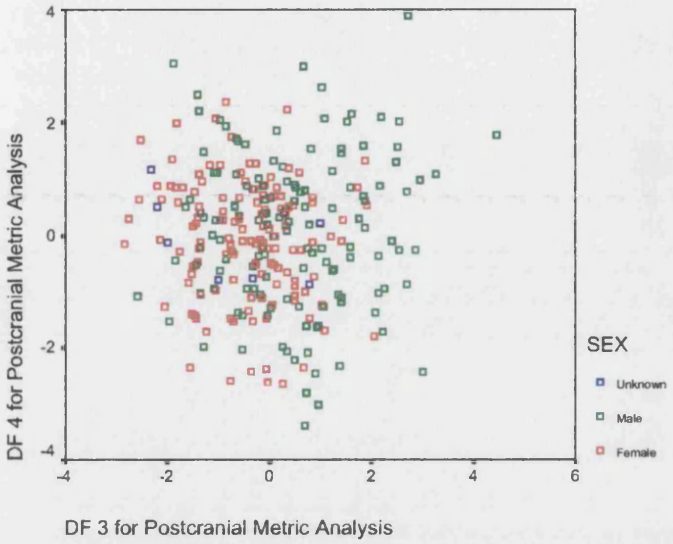


Figure 7.28 : Discriminant Functions 3 and 4 for Postcranial Metric DFA, by sex



Using the Discriminant Functions calculated from postcranial metric data to classify individuals into groups correctly classifies 56.5% of the data set (Table 7.18). The Andaman group is the only one in which all individuals are correctly classified, but the Kerma and Arikara have over 78% correctly classified. The Egyptian and Illinois populations are poorly classified, with fewer than 34% correctly classified. The manner in which individuals are mis-classified is also important. For the Avar and Poundbury populations, mis-classified individuals may be placed in almost any other population. The Inuit and Sadlermiut are most often mis-classified for each other, and the same is true for the Arikara and Illinois populations. Both of these pairs of populations are temporally, ethnically and geographically close.

Table 7.18: Classification Summary for Postcranial Metric DFA

Actual Population	Predicted population USB	AND	ARI	AVA	EGY	HAW	JCI	INU	KER	POU	PRH	SAD	Total
USB	14	0	1	3	2	0	0	0	3	3	0	0	26
AND	0	21	0	0	0	0	0	0	0	0	0	0	21
ARI	0	0	11	0	1	0	2	0	0	0	0	0	14
AVA	2	0	0	14	2	2	1	1	2	3	1	2	30
EGY	4	0	1	1	7	4	0	0	2	1	0	1	21
HAW	0	0	2	1	2	12	0	2	2	0	0	0	21
JCI	2	0	5	2	2	3	8	0	0	0	6	0	28
INU	0	0	0	2	0	2	0	21	0	1	1	7	34
KER	0	1	0	0	1	0	0	0	11	0	0	1	14
POU	3	1	1	2	1	1	1	2	0	13	3	3	31
PRH	0	0	0	0	1	0	1	1	0	4	13	0	20
SAD	0	0	0	0	0	1	0	3	0	1	0	11	16

Postcranial Scores Discriminant Function Analysis

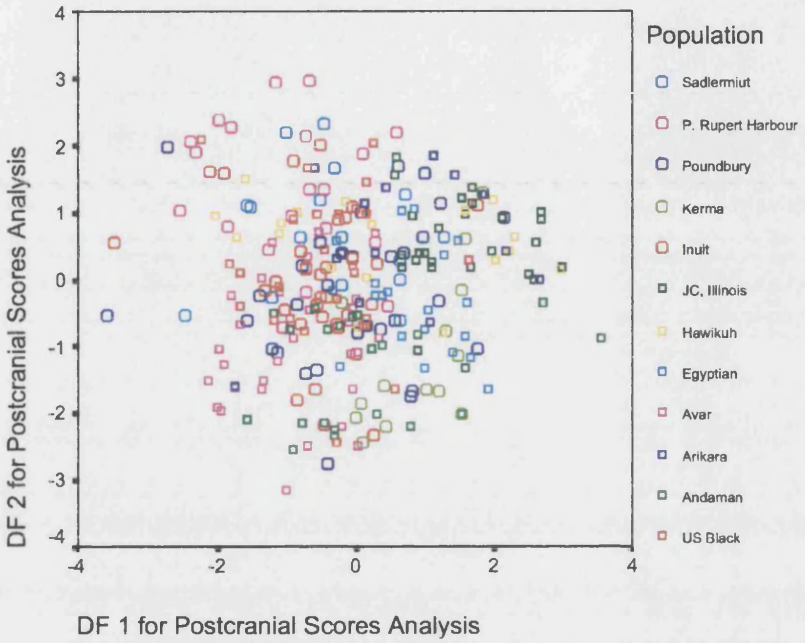
The eight variables used in this analysis are the scores for the ulna supinator and brachialis attachments, the femur gluteal and linea aspera, the tibial tuberosity, the humerus deltoid and bi-cuspid groove, and the score for wear at the radial head. The Discriminant Function Analysis (DFA) was carried out as for the postcranial metric analysis, and eight functions produced, although the first four explain 89.4% of the cumulative variance (Table 7.19). Variables were added in the descending order shown in the table.

Table 7.19: Discriminant Function Summary for Postcranial Scores Analysis

Function	Eigenvalue	Largest absolute variable/function correlation	% of Variance	Cumulative %	Canonical Correlation
1	.702		32.3	32.3	.642
2	.556	FGSCO, HDSCO, HBSCO	25.6	57.9	.598
3	.462		21.3	79.2	.562
4	.223	UBSCO	10.3	89.4	.427
5	.103	TTSCO	4.8	94.2	.306
6	.080	FPSCO	3.7	97.9	.272
7	.040		1.8	99.7	.196
8	.006	RHSCO, USSCO	.3	100.0	.078

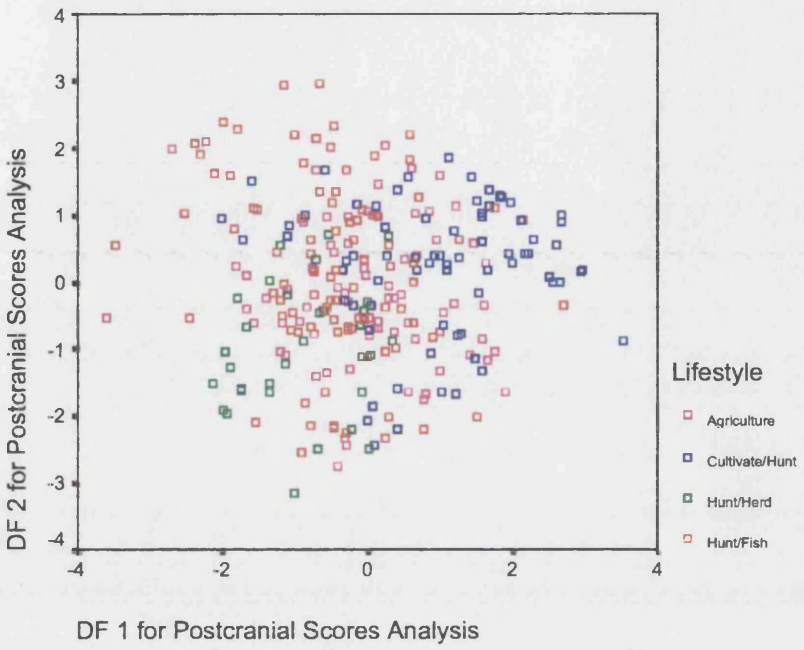
DFs 1 and 2 of the postcranial scores analysis separate the populations to some extent, although there is some degree of overlap (Figure 7.29). On DF 1, the Arikara, Egyptian and Illinois populations tend to cluster high, while the Avar, Prince Rupert Harbour, Inuit and Sadlermiut tend to cluster lower. On DF 2, the Avar, Kerma and Andaman populations score low, while the Prince Rupert Harbour and Hawikuh score high. DF 1 is associated with strong positive femur gluteal scores, but negative humerus scores, although these same three scores are associated more strongly and all positively with DF 2. DF 2 can be thought of as being general rugosity, while DF 1 reflects disconjunction between strong lower body rugosity and slight upper body rugosity.

Figure 7.29: Discriminant Functions 1 and 2 for Postcranial Scored DFA, by population



These same functions also produce some separation by lifestyle (Figure 7.30). Cultivate/hunt groups tend to cluster high on DF 1, being associated with high gluteal rugosity but not particularly strong humeral rugosity. The reverse is true for the hunt/herd groups, who cluster low on DF 1. DF 2 pulls the high-clustering hunt/fish and cultivate/hunt individuals away from the low-clustering hunt/herd groups, indicating that general rugosity levels are higher in the former than the latter lifestyle categories. No further functions produced separation when graphed by any categorical criteria.

Figure 7.30: Discriminant Functions 1 and 2 for Postcranial Scored DFA, by lifestyle



Using the postcranial scores analysis to classify the populations produced an accurate classification for 41.3 % of the individuals (Table 7.20). In no populations were all individuals correctly classified, and the populations more likely to have correctly-classified individuals varies considerably from the postcranial metric analysis (Table 7.18). The Prince Rupert Harbour individuals are the best classified, with 70% of them being correctly attributed to their true population. The other populations where more then 50% of individuals are correctly classified are the Andaman, Avar, Illinois, Kerma and Sadlermiut.

The Inuit and Poundbury are especially poorly classified, under 17% of individuals in these groups being identified correctly. On these postcranial rugosity grounds, the

Poundbury individuals are most likely to be mis-identified into one of the other European or North African populations (Avar, Kerma or Egyptian). The Inuit are likely to be mis-classified into almost any other population, but are most likely to be placed as Avar, Poundbury or Prince Rupert Harbour.

Table 7.20: Classification Summary for Postcranial Scored DFA

Actual	Predicted population												
Population	USB	AND	ARI	AVA	EGY	HAW	JCI	INU	KER	POU	PRH	SAD	**Total**
USB	7	2	2	1	1	1	1	2	3	1	3	2	26
AND	0	11	1	1	1	0	0	1	5	0	0	1	21
ARI	0	1	5	1	0	2	1	0	0	1	0	3	14
AVA	3	1	0	17	1	1	0	1	0	2	2	2	30
EGY	0	2	1	2	8	1	1	1	1	3	0	1	21
HAW	2	1	1	0	1	6	4	1	0	0	4	1	21
JCI	0	0	2	0	6	1	19	0	0	0	0	0	28
INU	1	3	0	6	0	3	1	5	2	5	5	3	34
KER	0	3	1	0	0	0	1	0	8	0	0	1	14
POU	3	1	2	5	5	1	2	0	4	5	2	1	31
PRH	1	1	0	0	1	2	0	1	0	0	14	0	20
SAD	2	0	0	0	2	1	0	0	0	1	1	9	16

Cranial Metric Discriminant Function Analysis

The eight variables used in this analysis are bi-zygomatic breadth (ZYB), bi-parietal breadth (XPB), palate length (PLL), orbit breadth (OBH), dacryon-dacryon breadth (DKB), parietal chord (PAC), foramen magnum length (FOL), and occipital chord (OCC). The analysis followed the same format as those above, and this time, the first four variables accounted for 89.6% of the cumulative variance (Table 7.21).

Table 7.21: Discriminant Function Summary for Cranial Metric Analysis

Function	Eigenvalue	Largest absolute variable/function correlation	% of Variance	Cumulative %	Canonical Correlation
1	1.778	DKB	39.4	39.4	.800
2	1.040		23.0	62.4	.714
3	.791	PAC, FOL	17.5	79.9	.665
4	.436	XPB, ZYB	9.7	89.6	.551
5	.351	OCC	7.8	97.3	.510
6	.080		1.8	99.1	.272
7	.029	PLL	.6	99.7	.167
8	.012	OBH	.3	100.0	.109

Graphically, Discriminant Functions (DF) 1 and 2 separate some populations reasonably well, while others exhibit considerable overlap (Figure 7.35). On DF 1, the US Black and Andaman populations cluster high, while the Inuit and Sadlermiut cluster low. This function relates to the distance between the eyes, measured from left to right dacryon (DKB). A large measurement here can be associated with classic African features, while the Arctic populations are known for narrow, pinched nasal bones.

DF 2 is associated with positive loading over .45 for bi-zygomatic breadth, palate length and orbit height, although all these variables load more strongly on other functions. The US Black individuals cluster high on this axis, while the Andaman, and to some extent the Kerma and Egyptian populations, cluster low. This function contains variables relating to facial height, width and prognathism, so score on this function relates to general face size.

Figure 7.31 : Discriminant Functions 1 and 2 for Cranial Metric DFA, by population

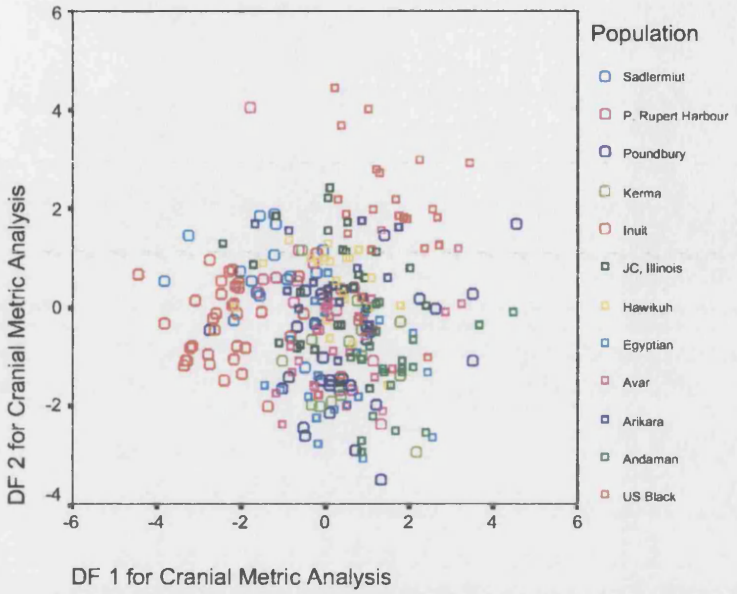
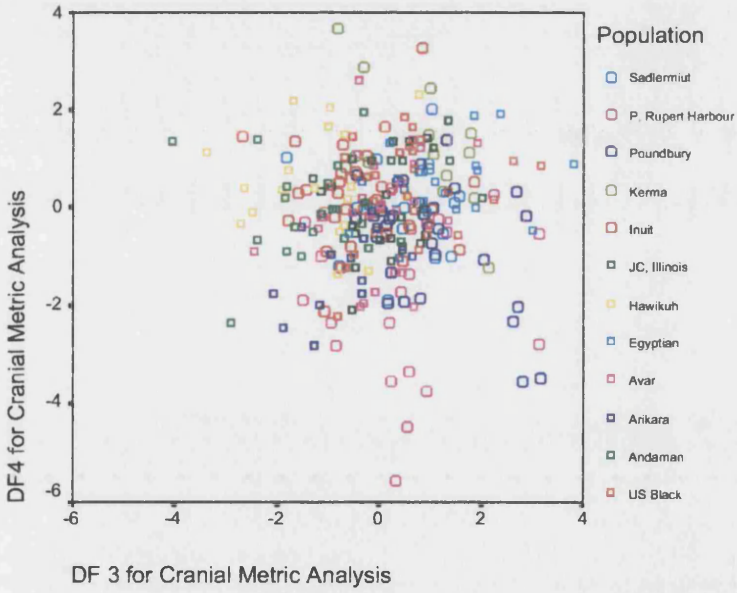


Figure 7.32: Discriminant Functions 3 and 4 for Cranial Metric DFA, by population



The third and fourth Discriminant Functions (DFs) also show some population separation (Figure 32). DF 3 is associated with parietal and foramen magnum length, and so relates to cranial length. DF 4 is associated with strong negative loading of bi-parietal breadth and bi-zygomatic breadth. From figure 7.32, it is clear that the Hawikuh have short, narrow cranial vaults, the Poundbury and Egyptian populations tend to have long crania, and the Prince Rupert Harbour population tends to have wide crania. There is no separation for these first four functions by other categories, nor for other functions by any category.

Using the cranial metric variables, 51.4% of individuals are correctly classified. The US Black, Andaman and Inuit are well classified (all over 73.5% accurate), unsurprisingly, since they have shown themselves to be distinctively clustered above. The Avar are the least well classified, with only 13.4% correct. The rest of the populations fall between 36% and 60% correctly classified (Table 7.22). The Avar are actually more likely to be classified as Egyptian, Illinois or Poundbury individuals than they are to be correctly identified. The Poundbury are also frequently mis-identified as Avar or Illinois individuals, and the Egyptian and Kerma are likely to be mis-classified as each other, Illinois, Poundbury or Avar. This cluster of populations are likely to be similar in terms of their cranio-facial metrics. The Inuit are most likely to be mis-classified as Sadlermiut, but the Sadlermiut are more likely to be mis-classified as Prince Rupert Harbour individuals.

Table 7.22: Classification Summary for Cranial Metric DFA

Actual Population	Predicted population USB	AND	ARI	AVA	EGY	HAW	JCI	INU	KER	POU	PRH	SAD	Total
USB	20	0	2	1	2	0	0	0	0	1	0	0	26
AND	0	18	0	0	0	1	0	0	1	1	0	0	21
ARI	1	0	7	1	0	0	3	0	0	0	1	1	14
AVA	0	3	1	4	5	1	7	2	2	4	1	0	30
EGY	1	0	1	3	9	0	1	1	2	3	0	0	21
HAW	0	1	3	1	0	12	1	1	1	0	0	1	21
JCI	3	0	3	4	2	2	10	1	0	0	0	3	28
INU	0	0	2	1	0	0	0	25	0	0	0	6	34
KER	0	0	0	0	3	0	2	0	8	1	0	0	14
POU	2	0	1	7	2	0	4	0	2	11	1	1	31
PRH	0	0	3	1	0	0	2	0	0	2	10	2	20
SAD	0	0	0	0	1	1	2	2	0	0	2	8	16

Cranial Scores Discriminant Function Analysis

The variables used in this analysis are supraorbital torus (ST), zygomaxillary tubercule (ZT), occipital torus (OT), zygomatic trigone (TR), occipital crest (OCR), orbital rounding (RO), orbit superior-lateral margin (OC), and orbit inferior-lateral margin (OB). The first five functions explain 94% of the cumulative variance (Table 7.23), but none of the functions produce good separation by population or other categories (Figure 7.33).

The best separation is by continent on DF 2 (Figure 7.38), in which the North Americans and Europeans tend to cluster at opposite ends of the axis. On the same scatter, the Asian continent tends to cluster low on DF 1, compared with the other populations. That continent should provide the best clustering is not surprising, since

the cranial scoring technique was designed specifically to explore regionally characteristic morphologies. However, it is not convincingly accurate at this scale, perhaps in part because the populations for which the techniques were designed (Australasian and South-East Asian) are under-represented in this restricted data set.

Table 7.23 : Discriminant Function Summary for Cranial Scores Analysis

Function	Eigenvalue	Largest absolute variable/function correlation	% of Variance	Cumulative %	Canonical Correlation
1	.666	OC	35.1	35.1	.632
2	.464		24.5	59.6	.563
3	.318	OT	16.7	76.3	.491
4	.179	TR, OCR	9.4	85.8	.390
5	.157		8.3	94.0	.368
6	.062		3.3	97.3	.241
7	.029	OB, ST	1.5	98.8	.167
8	.023	ZT, RO	1.2	100.0	.149

Figure 7.33: Discriminant Functions 1 and 2 for Cranial Scored DFA, by population

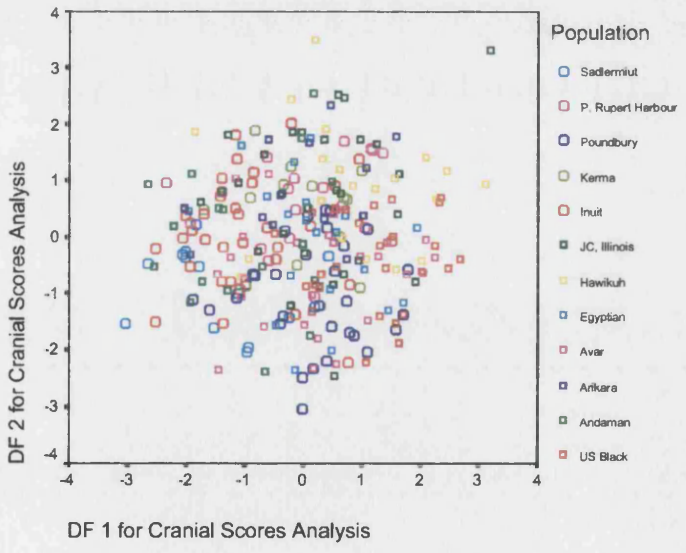
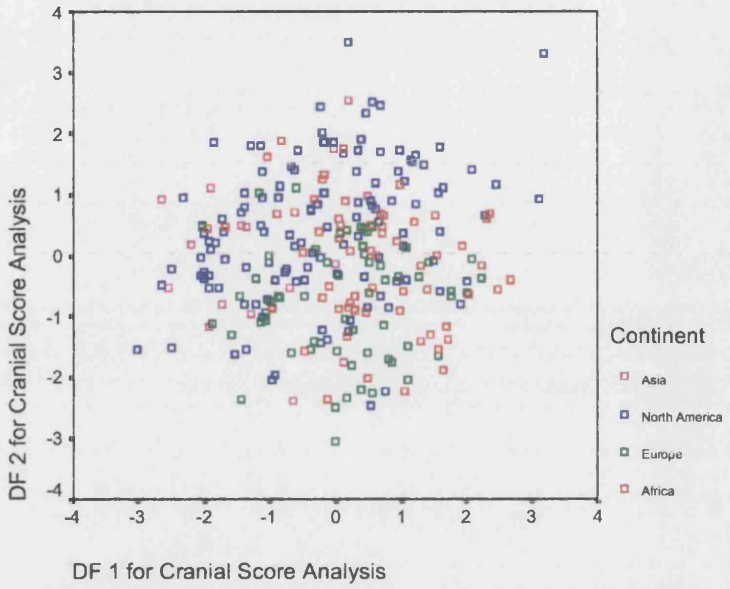


Figure 7.34: Discriminant Functions 1 and 2 for Cranial Scored DFA, by continent



Using these variables, just 38.4% of the individuals are correctly classified. None of the populations are entirely correctly classified, and only for only four, US Black, Hawikuh, Sadlermiut and Illinois, are more than 50% correctly classified (Table 7.24). The Inuit are most frequently mis-classified into one of the other Canadian groups, but the Sadlermiut and Prince Rupert Harbour populations are not preferentially mis-identified into other Canadian populations.

Table 7.24: Classification Summary for Cranial Scored DFA

Actual Population	Predicted population												
	USB	AND	ARI	AVA	EGY	HAW	JCI	INU	KER	POU	PRH	SAD	**Total**
USB	15	0	1	3	1	1	2	0	1	1	0	1	26
AND	1	9	1	3	1	1	0	2	1	1	0	1	21
ARI	0	2	4	0	1	3	0	0	1	0	3	0	14
AVA	1	5	1	9	4	0	1	1	1	4	0	3	30
EGY	3	1	1	2	4	2	0	0	4	3	0	1	21
HAW	0	1	3	2	1	11	0	1	1	0	0	1	21
JCI	1	1	0	1	1	1	15	1	2	3	2	0	28
INU	1	6	4	1	0	2	1	7	0	3	4	5	34
KER	1	0	2	0	0	2	2	1	5	0	0	1	14
POU	3	0	0	3	1	1	0	1	6	10	0	6	31
PRH	0	2	3	0	1	1	3	2	0	1	6	1	20
SAD	1	1	0	0	0	0	0	1	0	2	0	11	16

Discriminant Function Analysis Summary

The relative success of each Discriminant Function Analysis in classifying individuals is not as important as the patterns of mis-identification produced in each case. True theoretical equivalence between each of the variables used in each analysis is hard to demonstrate, although care has been taken to ensure as much fairness as possible. The same number of variables are used in each DFA, they have been selected following equivalent processes to determine the most successful and distinctive. However, the restricted data set may have had unequal effects on the utility of the variables chosen in each DFA.

To make a set of variables good at classifying individuals into populations, the variables have to be reliably discriminatory, and the populations used have to be

distinct. This means that variation in success at classifying could be because the variables used are more or less useful, or because the sample itself is more or less homogenous in that morphology. The two metric analyses perform better than the scores at classification, probably because of the difference between scaled and ordinal data. There is more scope for fine variation with metric measurements, and also, metric variables are well understood and have repeatedly tested for utility over the last two hundred years. Since the metric analyses use the best variables from a large selection of well understood variables, they are likely to include reliable variables. With scored data, there is a rougher approximation of form into an order, and less variation between individuals can be captured. In the scored data analyses, the variables are selected from a smaller sample of possible scored variables that are more recently developed and less well established than metric variables.

The postcranial DFAs perform better than cranial DFAs in classification. This may be because of the loss of many of the Asian and Australasian groups, who are distinctive in cranial form. The restricted data set retains the postcranially distinctive populations of the Americas. However, cranial form is well established as a marker of ethnicity, and with more variables it is likely that a cranial DFA could perform much better. The same may be true of the postcranial DFAs. The patterns of mis-identification in each DFA are very different, highlighting distinctive traits in each population. This is to be expected, given that each of the four analyses are focusing on different features.

The discriminant function analysis (DFA) for postcranial metrics produces separation between some populations, and distinguishes between them on the basis of shape. Narrow populations are distinguished from broad bodied groups in general terms, and specifically at the femur sub-trochanter region. The DFA for postcranial scores shows little population distinction, but does produce separation for lifestyle, showing that the scored data reflects activity patterns best. On the whole, the postcranial scored and metric data are assessing slightly different aspects of human skeletal diversity, but they have been shown above that they are not entirely independent, since climatic influence may act upon some variables in the same way.

The discriminant function analysis for cranial metrics produces clear population based separation, distinguishing between groups on the basis of their overall facial size and facial width. The DFA for cranial scores produces the least distinction between populations, but does provide some distinction between continents, which is to be expected, since that is exactly what the cranial scoring system was designed to do. As has been presented above, the cranial scores and metrics assess different aspects of craniofacial diversity, such that they can be considered independent of each other, as well as of postcranial variables.

Chapter 8 : Discussion

Each of the aims set out in Chapter 1 have been addressed. The success with which these issues have been dealt with will be discussed in this chapter. The findings of this study are discussed in depth, followed by an attempt to summarise the findings graphically (Figures 8.1 and 8.2)

Age and sex effects on robusticity and rugosity

The first aim was to establish how age and sex affect robusticity and rugosity. This was addressed using analysis of variance methods. Multi-way ANOVA was used to look at how significant age and sex are, once other influences are held constant, and one-way methods were used to investigate in more detail how the sex and age groups differ from each other in robusticity and rugosity.

Sex is one of the most important influences on postcranial size and robusticity, showing significant difference between males and females for all direct size measurements, even once other influences are held constant. Males are consistently larger than females for bone lengths, diaphyseal and epiphyseal dimensions. However, there is no significant effect of sex on body shape indices or diaphyseal circularity. Following the construction of robusticity indices, males are only more robust than females at the clavicle and humerus midshaft, and at the distal femur and proximal humerus epiphyses. In contrast to the significant effect of sex on

robusticity and size, postcranial rugosity scores show no sex influence in five-way analyses.

Age does not exert a strong effect on the postcranial skeleton. It shows no significant influence on any postcranial size, robusticity or rugosity variables, once other influences are held constant. Examined directly, postcranial rugosity scores do show a general increase with age, although some scores decline into the third age category from a mid-life peak. However, the wear rugosity scores do not stand out as having a particular relationship with age, any different to the general enthesis scores.

In the cranium, only cranial size (cranial module) is significantly different by sex, with males generally larger than females. There are no significant differences between age classes in cranial size, and none of the cranial robusticity indices show any age or sex influence, with other categories held constant.

In terms of cranial rugosity, sex does exert a significant influence, but only on the rugosity scores relating to trigones, tori and tuberosities. Males are more rugged than females for these regions, but aspects of cranial rugosity relating to nasal or orbit shape, occipital crest formation or sagittal keeling do not show significant sex differences. There is no significant age effect on rugosity, once other categories are held constant.

Both age and sex show significant interactions with each other and with other categories for many cranial and postcranial variables, which suggests that sexual

dimorphism and age-related change in skeletal morphology do vary considerably between the other sub-categories. This consistent interaction effect highlights the need to establish how age and sex affect different populations before comparing them as if they were equivalent. Using pooled-sex data for comparative studies could also lead to bias, if the level of sexual dimorphism differs in comparative sub-groups.

In the context of previous research, these findings are interesting. Age has been shown to be a significant effect on both robusticity and the cross-sectional properties of bone (Mays, 2000, Feik et al., 1996, Martin et al., 1985) as well as rugosity (Nagy, 1998, Weiss, 2001, Bridges, 1997, Merbs, 1983, Dutour, 1986), but only within groups. When compared across populations, as in this study, the age related patterns specific to each group may be lost. With robusticity, age-related increase up to peak working age is expected, and may be followed by robusticity decline in more sedentary life phases, or by changes in the way individuals respond to activity in later life (Woo et al., 1981). The timing and rate of these changes in activity is likely to differ between populations, based on the ecological demands of subsistence and habitat. This is supported by the frequent significant interactions between age and other categories, which show real differences between populations in the lifetime experience of their members.

The findings here support the work of Wilczak (1998), who demonstrated no significant age effect on enthesis size among females, and suggested that significant results discerned for age related increase in entheses among males could be due to the delayed maturation of males. Despite expectations that musculoskeletal markers

should increase with age, due to the slowing of remodelling (Mays, 2000) and the accumulation of injuries (Bridges, 1997), no universal trend in this direction is discernable, once other factors are held stable. This suggests that the process of enthesis formation and the maintenance of entheses is not well understood. Experimental attempts to influence the size of muscle attachments have been unsuccessful, (Zumwalt et al., 2001), but researchers have suggested that this might be because loading regimes were neither extreme nor prolonged enough to have any significant impact on osteogenesis at these locations. This also suggests that a certain amount of time is necessary for the effects of remodelling to be detectable, and relates to the expectation that enthesis expression will increase with age. However, in human archaeological data, if activity levels decline with age within a population, then remodelling to remove excessive hypertrophy may occur. As with robusticity decline, changes in the timing of this may obscure the picture in a study of several populations.

Wilczak also showed that sexual dimorphism in enthesis expression differed between diverse populations (1998), a finding supported here, and by other researchers (Ruff and Hayes, 1983). Where significant sex differences in rugosity and robusticity have been found, some researchers have attributed them to sexual division of labour, i.e. that they reflect real differences in activity (Ruff, 1987, Trinkaus, 1980). Other researchers have interpreted this as the consequence of allometric scaling (Weiss, 2001, Zumwalt et al., 2000) and the larger body size of males. A further alternative, outlined above in the context of cranial rugosity, is that

there is sexual selection for rugosity in males, particularly in the development of cranio-facial superstructures.

Comparisons between single sexes of related but different populations are useful and informative, because they avoid the confounding effects of the sex difference and its multiple potential causes. Steen and Lane (1998) use this technique to support ethnographic evidence that women of one Alaskan Eskimo population habitually chewed skins while those of another did not. Pooled sex data should thus be avoided, particularly in studies involving multiple ethnic groups.

Climate, lifestyle and continent effects on size, robusticity and rugosity

Lifestyle is the second major influence on postcranial size and robusticity after sex. The ulna and humerus functional lengths, the humerus midshaft and epiphyseal dimensions, and the robusticity indices for the radius, ulna and humerus midshafts, femur sub-trochanter, distal ulna epiphysis and proximal tibia epiphysis are all significantly different between different lifestyle strategies.

Significant climatic influences on postcranial size are restricted to the distal limb lengths. For the tibia, radius and ulna, functional lengths are shorter in cold climates, when all else is held constant. By continent, the only significant result is that ulna functional length is significantly shorter in Asia and the Americas than the other continents. There are no significant climatic effects on postcranial robusticity, either of the diaphyses or epiphyses.

This supports research showing that distal limbs are inherently more variable (Holliday and Ruff, 2001), and provides indirect support for the ecogeographic models used to establish migration and adaptation to climate in Pleistocene humans (Holliday, 1995, 1996, 1997, Churchill, 1999b). The speed at which body proportions can change is highlighted by Jantz and Jantz (1999), who show how secular change in less than a hundred years can significantly affect long bone length and body proportions. They also suggest that males respond skeletally to changes in health and nutritional standards to a greater degree than females, a position supported by Zakrzewski (2003), and further reason to separate the sexes in this kind of investigation.

Postcranial rugosity shows no significant influences from any of these factors, except on the femur pilaster, where climate, lifestyle and continent all show significance, even once other categories are held constant. Why just this one rugosity score should show a result is unclear, but the high scoring populations tend to be the taller groups. Having longer femora and hence longer muscles may enhance strain on the posterior femoral surface.

Examined through one-way methods, which are more susceptible to bias from the sample composition, there are some stable findings. Temperate and cold climates are both associated with higher rugosity scores than hot climates, but the effects are shown in different regions of the body. In general, the lower limb scores are less variable between continents and lifestyles than the upper limb and shoulder scores., which show more distinctive patterning by these categories.

High leg rugosity scores are associated with the cultivate/hunt category and the American, African and Australasian populations. Low leg rugosity scores are associated with the hunt/fish and hunt/herd peoples, Asian and European populations. It is notable that the cultivate/hunt strategy is associated with the highest leg rugosity, whereas the hunt/gather and stratified agricultural populations show only intermediate rugosity. The cultivate/hunt strategy incorporates activities from both a hunt and forage strategy and a horticultural strategy, which appear to place the greatest strain on the lower limbs. The hunt/gather strategy might arguably be more mobile and involve walking further, but it does not also require intensive cultivation, with the strenuous activities such as digging and hoeing involved. Equally, the populations representing later stage agriculture, are those where much of the population is essentially sedentary, placing lower demands on the body.

For rugosity of the upper arm and shoulder, high scores are associated with the hunt/gather, hunt/herd and hunt/fish lifestyles, perhaps through the impact of activities such as the spearing and dragging of animal carcasses, or live animal management. The wear score for the clavicle lipping behaves differently to the rest of the scores, indicating that it represents a different kind of rugosity information. Forearm rugosity is also high in hunt/herd groups, and the wear scores are lowest among hunt/gather and cultivate/hunt groups, and highest in hunt/herd groups.

Cranial size, robusticity and rugosity show no effects from climate, lifestyle or continent in multi-way analyses. For cranial size (cranial module), all three categories demonstrate significance at the one-way level, but graphically, the data for each

category show considerable overlap. For the cranial robusticity indices, there are no significant one-way effects. Cranial rugosity demonstrates some consistent trends in the basic data, in that certain categories are associated with higher proportions of some scores, but none of these translate into significant differences. Nonetheless, the populations are distinctive in their robusticity profiles, and several are well separated by the principal components analysis.

The cranial rugosity scores do not correlate to the activity and environment categories used in this study, despite previous research demonstrating activity related differences in rugosity (Steen and Lane, 1998), or arguing that climate could affect cranial rugosity (Hernandez et al., 1997). The scores themselves could be refined to focus more directly on muscle attachment sites, or the lack of significance could again be due to the aggregation of multiple populations.

However, neither do the cranial rugosity scores relate to the category of continent. These categories do not correspond to the main factors of distinctive cranial rugosity variation among populations. It is likely that neutral mutation, sexual selection and isolation produced the craniofacial differences between populations, rather than any external influences. However the continent categorisation is intended to group related populations to test for genetic effect. It should be refined on the basis of known genetic relatedness, and the analysis repeated to produce more reliable conclusions. This would be a promising further research direction.

Climatic and subsistence effects on postcranial robusticity have been reported previously (e.g. Pearson, 2000, Churchill and Morris, 1998, Bridges, 1989, Bridges et al., 2000), but this study only supports a significant effect of subsistence strategy in determining robusticity. The failure to demonstrate a significant climatic effect on robusticity, when other factors are held constant, is particularly interesting. Although distal limb lengths show some significant differences between climatic groups, this is not translated into significant differences in body proportions or robusticity.

It is the case that the multi-way ANOVA method used here means that variance in the sample is partitioned five ways, and indices are less variable than raw metric data. The failure to find a significant result may derive from a lack of variability in the data, and should be taken as absence of evidence, rather than evidence of absence of a relationship. Where significant climatic differences have been found elsewhere (Pearson, 2000), they may be due to the shortened limb, rather than to increased thickening, although steps are usually taken to counter this problem. The strong interactions between climate and lifestyle suggest that these are unlikely to be independent of each other, and disentangling the important relationships here may prove to require further study.

Body shape and size effects on robusticity and rugosity

One important question here is whether large individuals are more likely to be rugged or robust than small individuals. Large skull size, as recorded via cranial module, shows few significant relationships with cranial robusticity, but does show significant

relationships with cranial rugosity. The common association of sex with both size and rugosity could be part of this positive relationship, but it could simply be that larger skulls are more likely to be scored as rugged than small skulls.

Postcranial robusticity and size are generally correlated. Robusticity indices are size-corrected measures, and body mass is thought to be reflected in epiphyseal size. Epiphyseal robusticity indices correlate with diaphyseal robusticity, and residuals from these relationships show which populations are stronger than expected for their size. Epiphyseal robusticity is also related to postcranial rugosity, although the relationships show low explanatory power. Body size does exert some influence on robusticity and rugosity, meaning that larger bodies tend to be more rugged and robust than smaller bodies. The significant effect of sex on robusticity and rugosity is likely to be part of this effect.

The other important issue is whether shape affects the expression of robusticity and rugosity. Cranial shape (cranial index) only shows a significant relationship with frontal breadth index, among the robusticity indices, since both are essentially cranial width indices, but cranial index is also significantly associated with cranial rugosity and with cranial size itself. Body shape shows significant relationships with postcranial rugosity and robusticity. This range of findings demonstrates that cranial shape and body shape do affect robusticity and rugosity. This is likely to be because muscle complexes may operate with different lever advantages in different shape skeletal contexts.

The relationship between robusticity and rugosity

Postcranial rugosity and robusticity, and cranial rugosity and robusticity, both show weak but significant correlation. Robust crania or postcrania are more likely to be rugged than gracile elements. At the outset, it was argued that correlation between robusticity and rugosity would allow us to assume that robusticity indices and entheses access the same basic data about the skeleton, and both forms of remodelling are therefore likely to be triggered by the same biomechanical and endocrine experiences. This would not allow the identification of a systemic effect on bone remodelling.

Some correlation is to be expected, since human skeletons are integrated functional entities, and both robusticity and rugosity are assessed on nearby regions on the same skeletons. However, the large amount of unexplained variance in most of the relationships implies that robusticity and rugosity are recording two different systems for skeletal remodelling. Alternatively, either robusticity or rugosity may be more heritable than the other variable, or more susceptible to error or random effects.

This finding supports the continued study of entheses, since they therefore provide different information to robusticity analyses. Enthesis development has been shown to correlate with cross-sectional properties of bone (Berget and Churchill, 1994, Weiss, 2001), although Bridges (1997) found no significant relationship. Whereas Weiss argues that correlation between robusticity and rugosity highlights the

reliability of rugosity as a tool (2001, 2003), the degree of unexplained variance in the relationships described here shows that using both methods is not redundant.

Even if rugosity and robusticity had shown strong and direct correlation, enthesis assessment would still be informative, since rugosity scores allow the observer to pinpoint more accurately the nature or directions of strain experienced. Enthesis development may highlight the muscle groups most stressed or active in an individual, which have been most influential in producing the diaphyseal robusticity observed. Furthermore, enthesis development may allow characteristic activity patterns of people in a community to be determined, as long as a large sample is used. The fact that the relationships between rugosity and robusticity are weak enhances the utility of enthesis-based research, and suggests further research directions in establishing the strength of the relationship between rugosity and robusticity in particular elements. This would allow more information to be gathered from incomplete skeletal elements.

Figure 8.1 : Graphical summary of influences on postcranial morphology

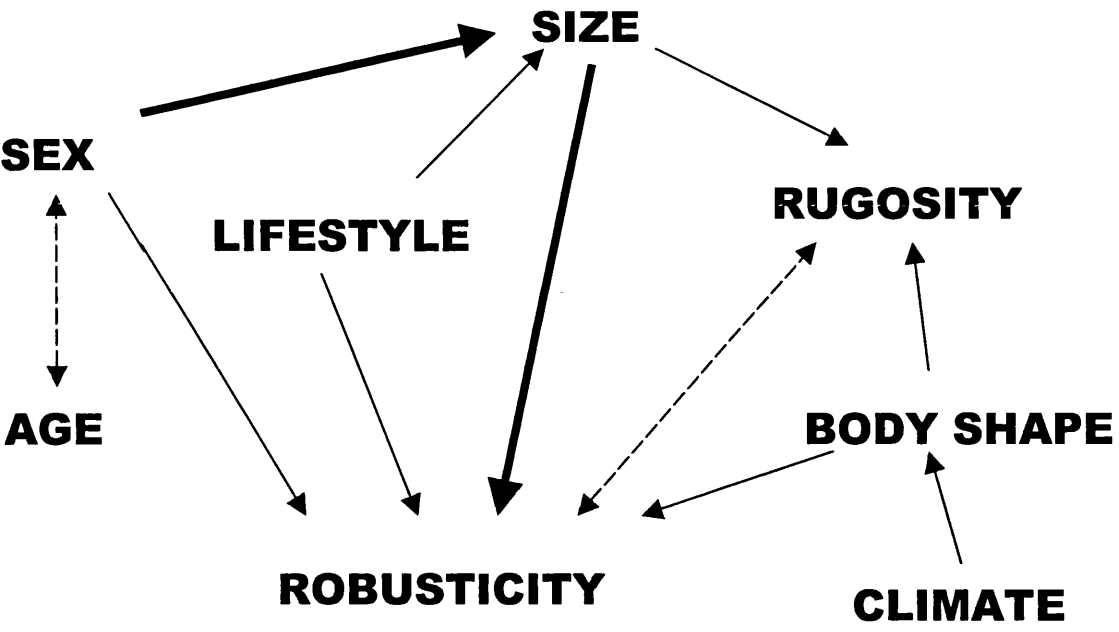
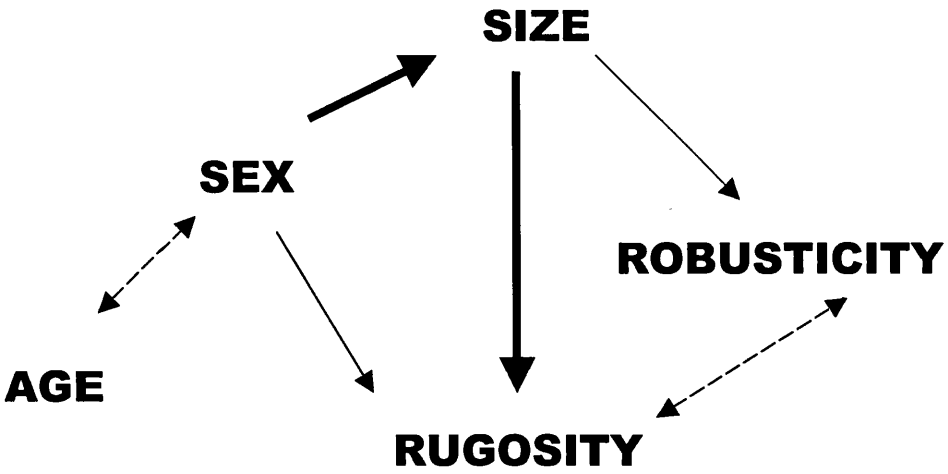


Figure 8.1 summarises the main influences on postcranial morphology, as determined by this study. Double ended arrows indicate interaction between actors, single arrows indicate the direction of influence. Strong arrows indicate the most important sources of influence, and dotted lines the least important relationships.The most important distinction that this graphic shows is that between direct and indirect sources of influence on postcranial morphology. Body size, sex and lifestyle can be seen as direct influences on postcranial robusticity and rugosity. Age and climate have indirect effect, only through their effect on sex or body shape respectively. Robusticity and rugosity interact to the extent that high levels in one factor correlate with high levels in the other. However, it is likely that the correlation comes from both rugosity and robusticity being under influence by the same demographic and environmental factors.

Figure 8.2 : Graphical summary of influences on cranial morphology



A graph of the same dynamics for cranial robusticity and rugosity reveals fewer influences from demographic and environmental factors (Figure 8.2). Sex is still a strong influence on cranial size, but does not relate strongly to robusticity, and only affects some aspects of cranial rugosity, specifically the craniofacial superstructures. Cranial size affects both rugosity and robusticity, but particularly rugosity, whereas the reverse is true for the postcrania. The same interactions of age and sex, and rugosity and robusticity are seen. Neither lifestyle, climate nor continent show direct or indirect influence on cranial rugosity and robusticity.

The relationship between cranial and postcranial expression of robusticity and rugosity

It is useful to know whether cranial and postcranial expression of robusticity and rugosity correlate. For example, when a large, robust and rugged skull or other element is examined, is it possible to assume that the rest of the skeleton was built on the same massive scale? This question has not been tested directly before, and the results of this study indicate that in general, cranial and postcranial variables demonstrate some significant relationships, but little explanatory power. Cranial robusticity is not significantly related to postcranial robusticity or postcranial rugosity, which means that in this global data set there are robust bodies with gracile crania, and vice versa. There may be a typical morphology for an ethnic group, where the relative degree of cranial and postcranial robusticity is within certain parameters. However, the high level of inter-group variation for these variables, as displayed in numerous boxplots above, produces considerable morphological diversity even within ethnic groups.

Cranial rugosity shows significant relationships with diaphyseal and epiphyseal robusticity, and with postcranial rugosity. In the latter case there is reasonably good explanatory power. So, rugged crania are more likely to be associated with robust and rugged postcrania. Since cranial and postcranial rugosity have traditionally been thought of in different ways and used to answer very different questions, this is very interesting. Further investigative research is necessary in order to establish whether

postcranial entheses are functionally equivalent to the various cranial rugosity features examined here.

As discussed briefly in Chapter 2, if cranial rugosity features do relate to muscular loading on the cranium and facial skeleton, then there could be some problems with treating them purely as markers of ethnicity. The converse problem is that postcranial entheses may not be entirely neutral of ethnicity. The results of this study highlight how it is important to apply the same theoretical standards to skulls and skeletons.

Further research into the heritability and ontogeny of entheses in different populations would be useful. Experimental work to see whether the same loading regimes produce varied enthesis expression among different individuals and ethnic groups would also be of critical interest, and may also produce much-needed information about the normal range of enthesis expression.

On evidence presented here, postcranial size, robusticity and rugosity respond to sex and lifestyle, with only minor influence from climate. Cranial size and rugosity respond to sex, but cranial robusticity shows no influence from any factors examined in this study. Although they combine to produce one functional structure, and there are several significant relationships between cranial and postcranial variables, there is still some measure of independence between them. This is supported by the Discriminant Function Analyses, which indicate that postcranial variables are better than cranial variables in classifying individuals into populations, perhaps because

there are more distinct morphological differences between ethnic groups in their postcrania than their crania.

Theoretical issues and implications

One of the most important points arising from this study is that skeletal data from diverse global populations must be treated carefully, or statistical problems are likely to occur. Design of comparative studies must aim to standardise or eliminate sources of variation as far as possible. Matching samples by age and sex is established good practice; it obviously makes sense to compare like with like. Levels of sexual dimorphism or age-related difference in the relevant variables must also be assessed, particularly if sex and age samples are to be pooled.

Where ethnically homogenous groups, living in the same place are compared, perhaps before and after a change in subsistence strategy, then at least climate and continent have been controlled, and one can be reasonably sure that differences observed (between demographically matched samples) are down to the lifestyle change. More problematic are studies where populations are selected on the basis of a single feature, and compared as if all the differences between them were down to that single feature. For example, a marine-mobile population compared with a land-mobile population, irrespective of other lifestyle factors, climate or ethnicity.

This study has also demonstrated, through comparing analysis of variance results with population-typical profiles, how the makeup of a data set can influence the

conclusions drawn. Even the most carefully constructed data set can be faced with this problem. The supply of curated human skeletal material is steadily shrinking, due to repatriation and decay. Many curated samples are used repeatedly, and have come to represent their original populations or subsistence strategies, or even to represent the whole region from which they originated. However, curated samples do not represent a neutral selection from that population. 'Interesting' specimens, perhaps displaying pathology or cultural modification, might be selected for retention over less distinctive ones. Hospital collections frequently sample only those individuals too destitute or disenfranchised to enable alternative post-mortem disposal. Archaeological collections may have a disproportionate representation of some age, sex or class groups, particularly if small, gracile individuals are more likely to be lost than large or robust ones.

The scarcity of varied skeletal material and reliance on a few classic collections results in a tendency for typical traits of that collection being discussed as though they were typical traits for the larger category of people that the collection is being used to represent. It may well be the case that these are reasonable assumptions, but they should be tested, for example by using several different samples who share the relevant trait, or by switching in alternative populations with similar traits to see how the findings are altered.

This study has also demonstrated the interdependence between climate, lifestyle and continent in the frequent interactions between these categories. The definitions of sub-groups within these categories are ambiguous though. It is not clear whether

a strategy described as hunting and gathering is really the same in different climates, or indeed different continents. Technological heritage plays an important role in cultural amelioration of the environmental circumstances, and so the material culture or behavioural traditions in different populations may play important roles in determining the range of activities performed within apparently similar subsistence or ecological situations. It may be more sensible to focus on individual ethnic groups through the production of population profiles, rather than aggregating them together in uncomfortable sets.

With studies of modern humans, even temporally distant populations, only one species is being examined, so a lack of variety in morphology is understandable. The converse situation, comparisons between more distant taxa such as species or sub-species, might well be expected to reveal differences in basic body proportion or cranio-facial morphology. But there are less clear-cut situations, such as in the comparison of early modern humans with late archaic humans or more recent moderns, where skeletal variation may reasonably be linked to climatic or activity-based differences, but where we know little about the other potential influences on the skeletal traits in question.

It is likely that this low variance in modern human morphology leads to the lack of significant findings using multi-way ANOVA in this study. Once this limited amount of variance has been partitioned five ways, then there just is not enough left over to prove a significant result. The argument here is not that the populations or sub-categories are the same, but that we cannot, with these data prove that they are

different. For this reason, the multi-way ANOVA method used in this study is an important tool to distinguish spurious relationships from those that can be statistically supported. It would be encouraging to see this method used in more studies, particularly where the problems of bias from sample composition are likely to be an issue.

Conclusions

The aims for this study have been successfully addressed, and the extent to which cranial and postcranial robusticity and rugosity reflect demographic, ethnic and environmental influences is better understood. We are now also closer to appreciating the normal range of human diversity in robusticity and rugosity world wide. This is important if trends in gracilisation and changes in rugosity are to be accurately interpreted. Thanks to the twin trends of gracilisation and encephalisation, recent modern humans may well be morphologically more similar to each other than to their immediate ancestors. However, there are still important, if subtle differences between modern human populations that can be useful for reconstructing typical life for that population, and individual experiences of activity and loading.

This study has demonstrated the utility of cranial and postcranial robusticity and rugosity as suitable data sources to investigate the influences on modern human morphological diversity. It has identified some important theoretical and statistical issues and advocates the need for caution in interpreting the results of similar studies. The results described here provide a platform for further research, that has the potential to provide insight into our understanding of modern human evolution.

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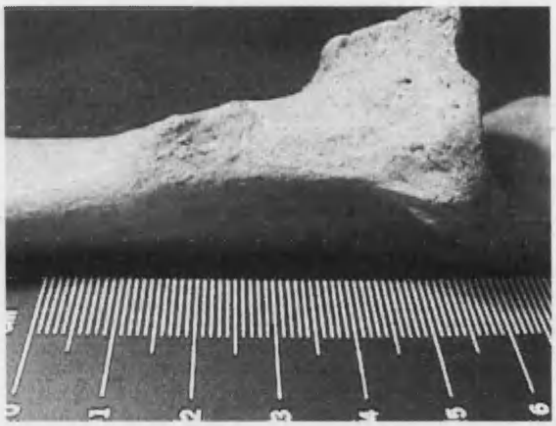
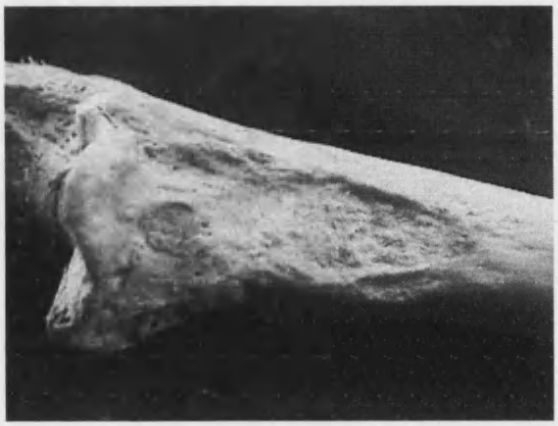
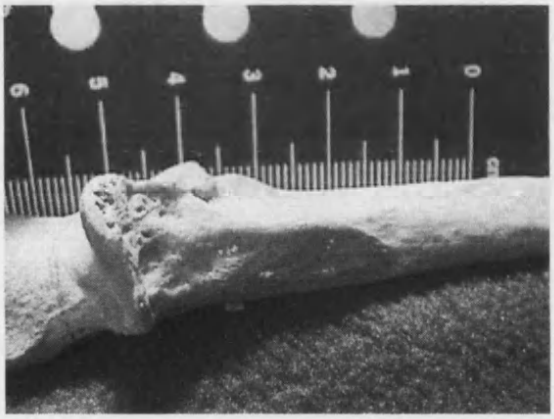
Appendix: Example images for scoring postcranial rugosity

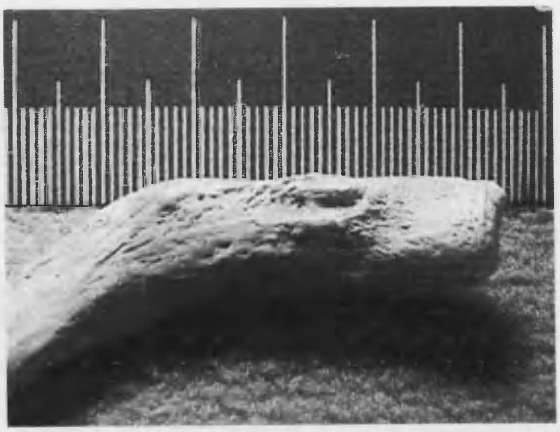
Ulna brachialis score: UBSCO 1-5

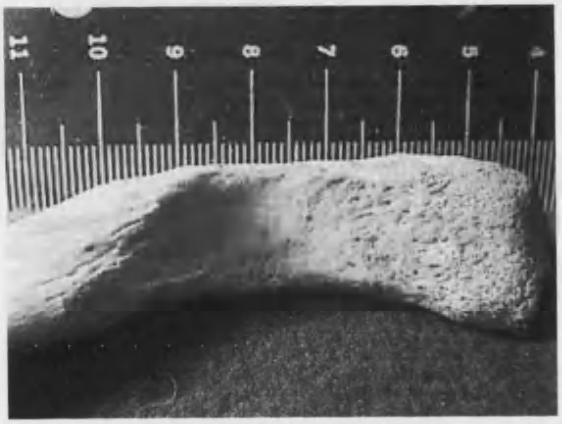


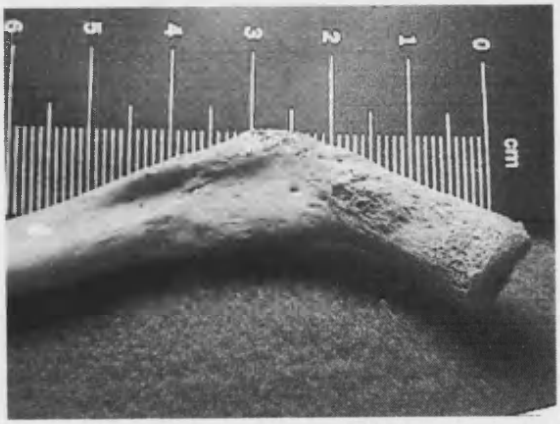


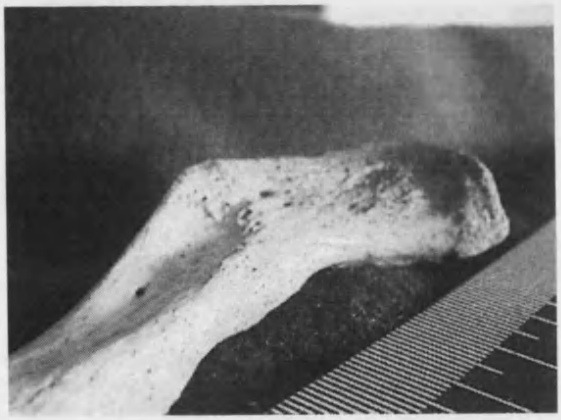


Clavicle distal ligament score: CDSCO 1-5

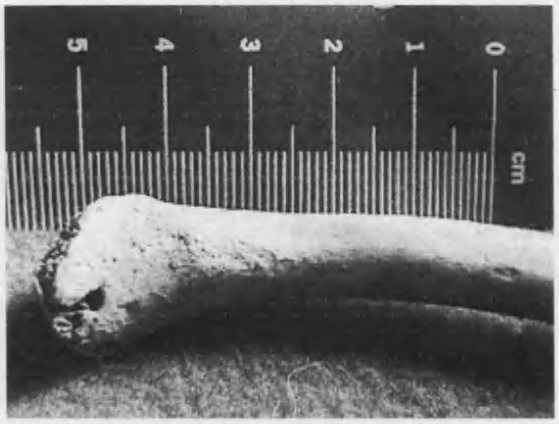


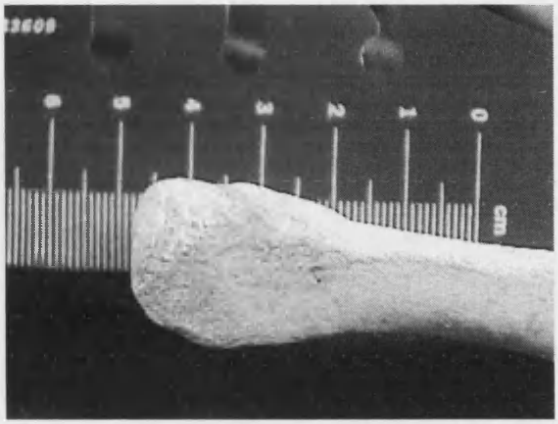


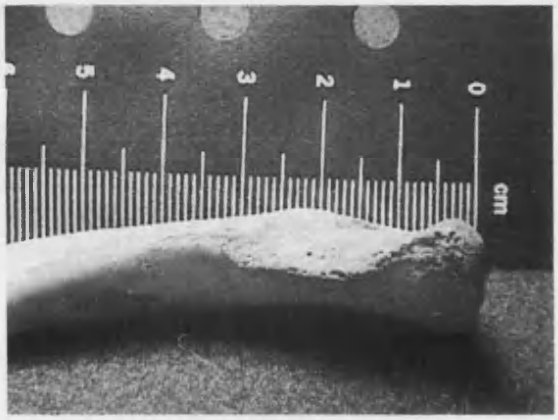


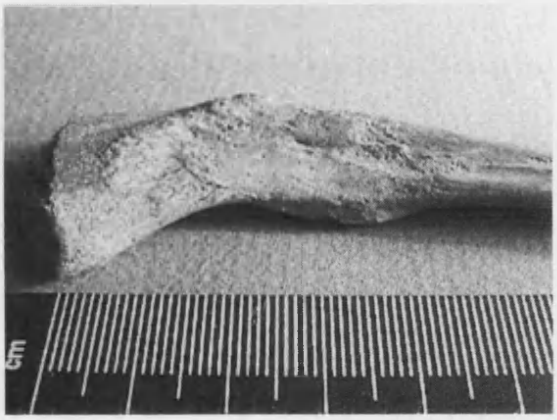


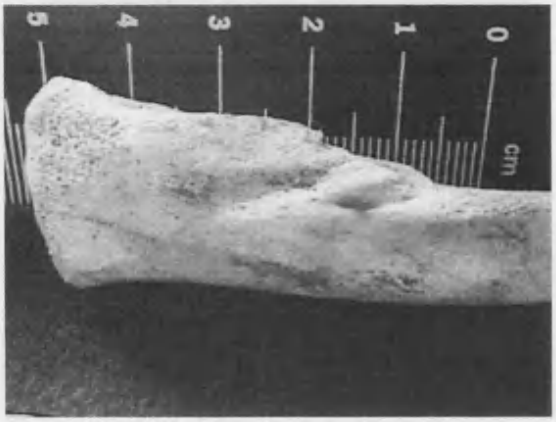
Clavicle sternal ligament score: CSSCO 1-5











Radius pronator score: RPSCO 1-5